ECOLOGY AND CONSERVATION OF THE ANASTASIA ISLAND BEACH MOUSE (PEROMYSCUS POLIONOTUS PHASMA)

By

PHILIP A. FRANK

A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1996

ACKNOWLEDGMENTS

First and foremost, I thank Steve Humphrey for his creative ideas, stimulating discussions, and professional leadership. John Eisenberg, Mel Sunquist, Ken Portier, and George Tanner also deserve thanks for serving on my doctoral committee.

I am grateful to the Florida Game and Fresh Water Fish Commission for funding this project. Thanks also go to the U.S. Fish and Wildlife Service, U.S. National Park Service, and Florida Department of Environmental Protection for their help in assisting all aspects of this project.

Volunteer field assistance was generously provided by Bert Charest, Alice Baird, Karen Lips, Kevin Frank, Myron Frank, and Weazie the Wonder Dog. Rebecca Henson deserves special recognition for assistance in trapping and vegetation sampling during long hours of shadeless summer heat. Fellow graduate students Brad Stith, Miriam Marmontel, Karl Miller, Carrie Sekarak, Bob Godshalk, Melissa Foster, John Polisar, Beth Forys, Ron Edwards, Dave Lambert, and Wendy Townsend provided the camaraderie essential for survival. My parents, Myron and Matty, and my brother Kevin deserve special thanks for their moral support and understanding of a decade of mice.

Finally, I thank the 2,244 beach mice captured during the study for their cooperation, and apologize for my periodic intrusions into their lives.

TABLE OF CONTENTS

page

ACKNOWLEDGMENTS . . . ii

ABSTRACT . . . v

CHAPTERS

1 INTRODUCTION . . . 1

The Beach Mouse . . . 1
Study Area . . . 2
Dissertation Goals and Structure . . . 6

2 POPULATION BIOLOGY . . . 10

Introduction . . . 10
Methods . . . 11
Results . . . 15
    Population Dynamics . . . 15
    Survival . . . 16
    Sex Ratio . . . 17
    Age Structure . . . 17
    Reproduction . . . 18
    Body Mass . . . 19
    Interactions with Domestic Cats and House Mice . . . 19
Discussion . . . 20
    Population Levels . . . 20
    Population Estimation . . . 22
    Survival . . . 23
    Interactions with House Cats . . . 24
    Interactions with House Mice . . . 26

3 DISTRIBUTION AND HABITAT . . . 43

Introduction . . . 43
Methods . . . 44
Results . . . 48

Island-wide Distribution of Rodent Species 48
Habitat Use by Rodent Species 49
Discussion 51
Beach Mouse Habitat Use. 51
Habitat Use by Exotic Species 52

4 RE-ESTABLISHMENT 64

Introduction 64
Methods 65
Results. 68
Distribution 68
Population Monitoring 69
Comparison with Anastasia Island Population 70
Discussion 70
Population Vulnerability 70
Habitat Use 71
Differences between Anastasia Island and GRSP 72

5 POPULATION VIABILITY ANALYSIS 77

Introduction 77
Methods 79
Results. 83
Discussion 85

6 MANAGEMENT RECOMMENDATIONS 94

Management Philosophy and Goals 98
Proposed Management Actions 99
Population Monitoring 99
Habitat Management 101
Domestic Cat Control 102
Range-wide Management 103
Catastrophe Planning 103

REFERENCES 105

BIOGRAPHICAL SKETCH 111

Abstract of Dissertation Presented to the Graduate School of the
University of Florida in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy

ECOLOGY AND CONSERVATION OF THE ANASTASIA ISLAND BEACH MOUSE (PEROMYSCUS POLIONOTUS PHASMA)

By

Philip A. Frank

December, 1996

Chairman: Stephen R. Humphrey
Major Department: Wildlife Ecology and Conservation

The Anastasia Island beach mouse (Peromyscus polionotus phasma) is an endangered rodent endemic to northeastern Florida. Coastal development has reduced both the quantity and quality of the remaining habitat. As a result, populations of the Anastasia Island beach mouse are reduced, fragmented, and at risk to extinction. A two-year study was conducted to document beach mouse population ecology, effects of exotic house mice (Mus musculus) and domestic cats (Felis cattus), habitat requirements, and threats to their continued persistence.

Live-trapping was conducted quarterly on seven 1-ha grids from January, 1989 through October, 1991. A total of 23,200 trap nights were accumulated, and a total of 1,668 beach mice were captured on 4,230 individual occasions. Beach mouse populations fluctuated between approximately 10 to 100 per ha at a single location. House mice did not negatively affect beach mouse populations, but occupied similar habitat. House cats preyed upon beach mice and may negatively affect beach mouse populations.

Habitat requirements of rodents on Anastasia Island were studied on live trapping transects. Specific patterns of habitat use varied by species: beach mice and house mice preferred primary dunes; cotton rats (Sigmodon hispidus) preferred dense, grassy areas and stable dunes; and black rats (Rattus rattus) preferred stable dunes. Primary dune habitats adjacent to development supported beach mouse densities typically one-half that of undeveloped habitats.

Beach mice historically occupied both Anastasia Island and the un-named barrier island immediately to the north, but were subsequently extirpated from the northern island. A relocation of 55 adult beach mice was conducted to publicly-owned property during October, 1992. The population rapidly beacme established and expanded over a 6.5-km beach area. Post-release monitoring documented the persistence of this population through October 1994.

A simple model of beach mouse population dynamics was developed to examine the effects of catastrophic storms on population persistence. Frequent but less severe hurricanes such as Category I and II pose a much greater threat than do extremely rare catastrophic Category V storms. Recommendations for beach mouse management include regular monitoring of populations, maintenance of optimal habitat conditions, and the establishment of additional protected populations in captivity.

CHAPTER 1
INTRODUCTION

The Beach Mouse

The oldfield mouse (Peromyscus polionotus) is a small nocturnal rodent that ranges throughout the southeastern United States including portions of Alabama, Georgia, South Carolina, and Florida (Hall 1981). Subspecies of the oldfield mouse that occur on coastal beach dunes of portions of Alabama and Florida are generally paler than inland forms and are collectively referred to as beach mice. Because of extensive development of coastal areas, beach mice have experienced extensive loss of their preferred dune habitats. Consequently, of the eight recognized subspecies of beach mice, six are listed as either threatened or endangered by the U.S. Fish and Wildlife Service and Florida Game and Fresh Water Fish Commission, and the pallid beach mouse (P. p. decoloratus) is extinct (Ehrhart 1978, Humphrey and Barbour 1981, U.S. Fish and Wildlife Service 1987).

The situation faced by the Anastasia Island beach mouse (P. p. phasma) typifies the plight of beach mice throughout their range The subspecies has a restricted range, occurring on only two barrier islands in St. Johns County, Florida. Prior to the initiation of this project, the range included only a single island (Humphrey and Frank 1992) but was expanded to include an island where the Anastasia Island beach mouse was recently extirpated (Chapter 3, Ivey 1949, 1959). The Anastasia Island beach mouse is a habitat specialist, occupying the narrow strip of dunes on the Atlantic coast of the island (Pournelle and Barrington 1955). The availability of this naturally limited habitat has been severely reduced, degraded and fragmented by coastal development. Exotic house mice (Mus musculus) and domestic cats (Felis sylvestris) have colonized the dune habitats preferred by the Anastasia Island beach mouse and may pose a serious threat to the remaining population (Blair 1951, Bowen 1968, Humphrey and Barbour 1981, Frank 1992). Finally, hurricanes are a regular albeit unpredictable feature of beach mouse habitat on Anastasia Island and elsewhere. These severe storms can destroy large amounts of beach mouse habitat, posing a serious and unpredictable threat to beach mouse populations.

Study Area

Anastasia Island is a barrier island located in northeastern Florida, in St. Johns County, and is the southernmost island in a series of southern sea islands sharing similar natural and culture histories (Johnson and Barbour 1990, Figure 1.1). The island is a long, thin formation extending 22.2 km north-to-south and ranging from approximately 0.5 to 3.0 km in width east-to-west. It is separated from mainland Florida by extensive salt marshes and the Matanzas River, to the north by the St. Augustine Inlet, and to the south by the Matanzas Inlet. The seaward side of the island is bounded by the Atlantic Ocean and is composed of fine quartz sands that form the beaches and dunes. A wide beach berm slopes gently upward from the shoreline to the outer dunes, which form a continuous ridge paralleling the ocean.

The dune vegetation on Anastasia Island can be classified into general zones: foredunes, transitional dunes, and stable dunes (Johnson and Barbour 1990, Figure 1.2). These distinct zones vary in topographic and vegetative structure, distance from the high water level, elevation, stability, and plant species composition. Detailed descriptions of plant communities typical of this region can be found in Johnson and Barbour (1990), Lassle and Monk (1961), and Kurz (1942).

The zone nearest the shoreline is the upper beach and foredune (Johnson and Barbour 1990), a sparsely vegetated, low-elevation zone subject to continual disturbance from wind and wave erosion. The height of foredunes ranges between < 1.0 m to 4-5 m. Vegetation on the foredunes is generally sparse, consisting of salt-tolerant pioneering species adapted to the harsh conditions. Sea oats (Uniola paniculata) is the most abundant and important dune-forming species, trapping sand and stabilizing the dunes. Railroad vine (Ipomea brasiliensis) and beach morning glory (I. stolonifera) are also common pioneer species playing an important role in early dune formation. Other species frequently encountered on the foredunes include beach elder (Iva imbricata), pennywort (Hydrocotyle bonarenensis), sandspur (Cenchrus spp.), beach panic grass (Panicum amarum), and evening primrose (Oenotheria humifusa).

Behind the foredunes is the transitional zone or backdune, which begins at the foredune and continues inland until a distinct plant community is recognized (Johnson and Barbour 1990), usually scrub, hammock, or salt marsh on Anastasia Island. The width of this zone is variable, ranging from less that 10 m to 100 m or more. Vegetation in the transition zone is highly variable and usually includes species found on the foredunes as well as plants from inland communities. The transitional vegetation on Anastasia Island is generally sparse and low compared to more southern barrier islands, although dense, grassy swales composed of beach cord grass (Spartina patens) and purple muhly grass (Muhlenbergia capillaris) are present in a few locations.

Herbaceous species common in the transition zone include many found on foredunes as well as camphorweed (Heterotheca subauxillaris), firewheel (Gaillardia pulchella), beach croton (Croton punctatus), prickly pear (Opuntia humifusa) and devils joint cactus (O. pusilla), greenbriar (Smilax auriculata), plus a variety of grasses and forbs. Shrubs and trees that may occur in the transition zone include wax myrtle (Myrica cerifera), Atlantic cedar (Juniperus siliciola), scrub oak (Quercus virginiana), saw palmetto (Serenoa repens), and red bay (Persea borbonia). Because wind and salt-spray retards growth of trees and prunes distal ends of shoots in the transition zone, most specimens encountered are 2.0 m or less in height. Coastal scrub was previously widespread on Anastasia Island, but development has reduced it to a few small patches.

Stable dunes are most interior, highest in elevation, oldest, and most stable (Johnson and Barbour 1990). Elevations of stable dunes on Anastasia Island reach as high as 10-12 m, but these formations are absent in many areas on Anastasia Island as a result of development. The principle vegetation type on stable backdunes is oak forest or hammock. The primary species in the oak forest is live oak (Q. virginiana), forming a closed canopy in most places, with the crowns often sculpted by wind and salt spray to a uniform level. Other species capable of reaching canopy height include slash pine (Pinus elliottii), southern magnolia (Magnolia grandiflora), red bay, Atlantic cedar, and cabbage palm (Sabal palmetto).

The understory of the oak hammock can be quite dense in places, but is generally open. A well-developed layer of leaf litter is usually present, and little sunlight reaches the ground. A variety of woody species commonly are encountered in the understory including red bay, southern red cedar, and southern magnolia. Non-woody understory species commonly encountered include saw palmetto (Serenoa repens), American beauty berry (Callicarpa americana), vines (Vitus spp.), plus many others.

Human disturbance has greatly reduced the amount of available beach mouse habitat on Anastasia Island, especially transition zone habitats directly behind the foredune. Development consisting of single-family homes, condominiums, and commercial uses are typically placed as close to the beach as possible, leaving only a narrow strip of dune vegetation between the structure and the beach. Presently, nearly all of the dune habitat on Anastasia Island is either developed or under public ownership. Of the approximately 22 km of frontal dunes on the island, 8.5 km are under public ownership by the State of Florida Department of Environmental Protection and the National Park Service. One large tract of undeveloped beach mouse habitat approximately 1.6 km in length still exists near the central portion of the island, but the owner is seeking permits to develop a planned community at this location. For all practical purposes, the amount of beach mouse habitat dedicated for preservation purposes on Anastasia Island has been determined.

Dissertation Goals and Structure

The goal of this dissertation is to provide the essential ecological information required to permit informed decisions regarding the management of the Anastasia Island beach mouse. The dissertation is organized into six chapters and is based on two years of field work conducted on Anastasia Island from December, 1989 through January 1992.

Chapter 2 summarizes the 24-month live trapping study and provides information on the general population ecology of the Anastasia Island beach mouse. This chapter includes basic information on population trends, age structure, sex ratio, body mass, movements, reproduction, and survivorship. This chapter also examines the relationship between beach mouse populations and the introduced populations of the house mouse and domestic cat that are established on Anastasia Island.

Chapter 3 provides a quantitative analysis of the structure and composition of the various dune habitats on Anastasia Island. This chapter also examines the specific patterns of habitat use by the four rodent species that commonly occur on Anastasia Island. A quantitative analysis of the amount of dune habitat that remains was conducted using a GIS, and using the population estimates from Chapter 2, an estimate of the total population of beach mice on Anastasia Island is made.

Chapter 4 describes an effort to expand the range of the Anastasia Island beach mouse to an adjacent barrier island that was within the historic range. Beach mice were relocated from populations on Anastasia Island to Guana River State Park during October, 1992. This introduced population was monitored for two years to determine the success of the re-established population.

Chapter 5 develops a population model to test predictions regarding the long-term persistence of the Anastasia Island beach mouse in the face of periodic severe coastal storms. Information on population densities, survival rates, and fecundity were incorporated into a stochastic simulation model that was subjected to a variety of catastrophe parameters to simulate the effect of hurricanes on the population persistence. Predictions on the fate of the beach mouse population were then tested over a 50-year period.

Chapter 6 provides recommendations for the future management of the Anastasia Island beach mouse. In addition to standard recommendations on population monitoring and habitat protection, the dilemma of ecosystem vs. single-species management strategies is discussed in light of the conditions that currently exist on Anastasia Island.

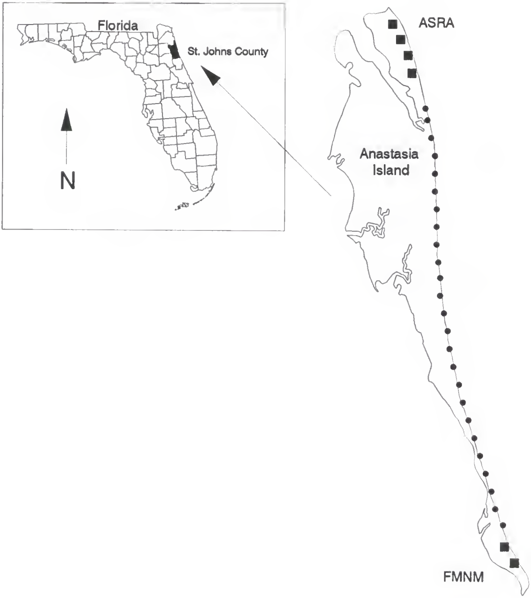

Figure 1.1. Location map showing St. Johns County, Florida and Anastasia Island. Also depicted are trapping grids (squares) at Anastasia State Recreation Area (ASRA) and Fort Matanzas National Monument (FMNM) and trapping transects (circles) along the length of the island.

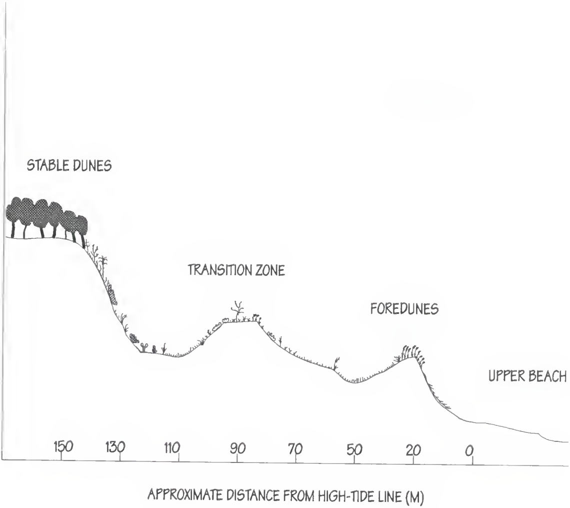

Figure 1.2. Graphic representation of the three types of dune vegetative communities found on Anastasia Island: foredunes, transitional dunes, and stable dunes.

CHAPTER 2
POPULATION BIOLOGY

Introduction

The Anastasia Island beach mouse is one of over 500 plants and animal species listed as endangered in the United States. It was listed as endangered in 1989 by the U.S. Fish and Wildlife Service based on its limited distribution, the extent of habitat loss, and the degradation of the remaining habitat (U.S. Fish and Wildlife Service 1989). At the time of listing, little was known about the biology of this species except that beach mice still occurred on Anastasia Island and the remaining population was vulnerable to extinction (Humphrey et al. 1987).

The population ecology of the Anastasia Island beach mouse has not previously been studied, and current information on the ecology of this species will facilitate the protection of the remaining populations. Comparable studies on other beach mouse taxa are those by Blair (1951) on the Santa Rosa Island beach mouse (P. p. leucocephalus), Kiem (1979) and Extine (1980) on the southeastern beach mouse (P. p. niviventris), and Rave and Holler (1992) on the Alabama beach mouse (P. p. ammobates). While these studies provide valuable insight into beach mouse conservation, a study specific to the conditions of the beach mouse population on Anastasia Island is needed.

The objective of this chapter to provide basic information on the population ecology and life history of the Anastasia Island beach mouse. Beach mouse populations were studied for two years on Anastasia Island to determine seasonal variation in population density, survivorship, reproduction, sex and age composition, and interactions with exotic house mice and feral cats.

Methods

Two study sites were selected based on the existence of undeveloped dune systems and were located at the extreme north and south ends of the island. To the north is Anastasia State Recreation Area (ASRA, Florida Department of Environmental Protection) with 5.6 km of dunes. To the south is Fort Matanzas National Monument (FMNM, National Park Service) with 2.9 km of dunes. Vegetation is generally similar at both sites with foredunes vegetated mainly by sea oats (Uniola paniculata). Although undeveloped, these habitats are impacted by foot traffic and littering from large numbers of beach visitors. Vehicular traffic is permitted on the beaches at both locations, further increasing the amount of habitat disturbance.

Beach mouse population ecology was studied by mark-recapture on a series of trapping grids. Each grid was 1 ha, with a 10 x 10 matrix of 100 trap stations each spaced at 10 m intervals. Grids were oriented with the first row parallel to the beach on the crest of the foredunes and the remaining rows extending landward. All trap stations on the grids were in habitat judged suitable for beach mice. Five trapping grids were established at ASRA; four (AI1, AI2, AI3, AI4) were established in January 1989 and a fifth (AI5) was established in June 1989. The minimum distance between grids at ASRA was 200 m. Two grids were established at FMNM (FM1, FM2) and were closer (60 m) than ASRA grids.

Trapping was conducted quarterly from January 1989 to January 1991, corresponding to the four seasons: winter (January), spring (April), summer (July), and fall (October). All grids were trapped from January 1989 to January 1991 except that trapping on AI5 did not begin until June 1989 and trapping at ASRA in January 1991 included only AI1 and AI3. Because trap disturbance essentially was absent throughout the study, trap nights were not adjusted for the occasional sprung trap. Each trapping session lasted 4 consecutive nights regardless of weather conditions. A single large Sherman trap (model LFTAG, Sherman Live Traps, Tallahassee, Florida) baited with a mixture of rolled oats and peanut butter was set at each station in the afternoon and checked and closed the following morning. During cold weather, cotton was placed in the traps to provide captured mice with insulation. Traps were cleaned following each trapping session.

To estimate the relative abundance of domestic cats on the trapping grids, a count of cat tracks was made while baiting the traps in preparation for the first day of trapping. The number of times cat tracks crossed a grid line was recorded. No attempt was made to distinguish between individual cats occurring on the grids. Instead, cat track occurrence was used as an index of cat activity on the grids.

The grid location, species, sex, age, mass, and reproductive condition were recorded for each capture. Age was determined from pelage condition; juveniles had all-gray pelage, subadults still possessed juvenile pelage but had begun molting into adult pelage, and adults possessed complete pelage of adult color. Males were considered reproductively active if the testes were well developed and descended into the scrotum. Positive evidence for female reproduction consisted of enlarged and lactating teats or obvious pregnancy. Rodents were weighed to the nearest 0.5 g using a Pesola spring balance. All rodents were individually identified by numbered monel tags placed in the ear.

A combination of open and closed models were used to obtain estimates of population size, survival, and recruitment (Pollock 1982, Pollock et al. 1990). Beach mouse population estimates were obtained using closed models in the program CAPTURE (Otis et al. 1979). CAPTURE models known sources of variation in trap response by members of the population, providing a statistically-based description of population size (Nichols and Pollock 1983). Sources of variation include differences in trapability over time (model T), between individuals, sexes, or age classes (model H), and positive or negative behavioral responses to traps (e.g., trap-happy vs. trap-shy, model B), and combinations of these factors. The NULL model assumes equal trapability between all individuals in the population. A model selection procedure in CAPTURE selects the model that best fits the data and uses this model for population estimation. In those cases where no estimator was available, the best fit model was manually selected for use in population estimation.

CAPTURE is a closed population model, assuming no individuals leave or enter the population during the census. This assumption is tested using a procedure in

CAPTURE, and the short duration of trapping sessions (4 days) favored closure in the population. At least 20 individual captures and average capture probabilities >0.30 are recommended for accurate population estimation using program CAPTURE (White et al. 1982). Simple count statistics were calculated for comparison with CAPTURE estimates.

Analysis of variance was used to detect seasonal differences in population estimates within and between study sites using means of population estimates obtained from program CAPTURE. Data were log-transformed prior to testing for normality and common variance. Non-parametric statistical tests were used on any data failing to meet normality assumptions required for the parametric tests.

Estimates of survival between sampling periods were obtained using the Jolly-Seber open population models (Pollock et al. 1990). These models do not assume population closure and are robust to unequal catchability among members of the population (Pollock et al. 1990). A simple survival rate estimator was also calculated by comparing the number of mice marked in a session to those known to survive until the following session. An additional measure of survival was determined by estimating the mean age of mice at each study site by determining the minimum number of days each mouse was known to have been present on a grid. Adult mice were assumed to be a minimum of 40 days old, subadults were 30 days old, and juveniles were 20 days old (Layne 1968).

Sex and age ratios were compared with chi-square tests and non-parametric proportion tests. T-tests were used to compare mass between locations, seasons, and sexes.

Results

Population Dynamics

A total of 23,200 trap nights was obtained during the study: 16,000 trap nights on the five grids at ASRA and 7,200 trap nights on the two grids at FMNM. A total of 1,668 beach mice was captured on 4,230 individual occasions; 1,254 mice were captured 3,113 times at ASRA and 414 mice were captured 1,117 times at FMNM. The number of individuals captured per grid, the total number of captures per grid, capture probability, model selection, and population estimates were calculated by grid for all trapping sessions (Table 2.1).

Within each study area (ASRA and FMNM), data from the grids was pooled and averaged to examine seasonal trends in population size (Figure 2.1). Population levels at ASRA were at low densities through 1989 but increased significantly in January 1990. The ASRA population remained at high densities through 1990 relative to 1989 and increased significantly again in January 1991. Estimated population size at ASRA ranged from was 2 individuals (January 1989-AI3) to 90 individuals (January 1991-AI1). Estimated population size at FMNM was higher relative to ASRA in the first half of 1989 but decreased throughout the second half of 1989. Density increased significantly from October 1989 to January 1990, and then decreased significantly in April 1990. Population size at FMNM then declined gradually through the remainder of the study (Figure 2.1). The range in estimated population size at FMNM was 14 individuals in October 1989 (FM1) to 47 individuals in January 1990 (FM1).

Population size at FMNM was significantly greater than ASRA in January 1989

(F = 9.8, P = 0.03, df = 1) and population size at ASRA was significantly greater than FMNM during April 1990 (F = 13.7, P = 0.01, df = 1), October 1990 (F = 10.7, P = 0.02, df = 1), and January 1991 (F = 105.4, P = 0.01, df = 1).

Survival

Maximum longevity for an individual mouse in this study was 600 days, and eight individuals lived 550 days or longer (Figure 2.2). Mean longevity of beach mice at both study areas combined, including all age classes, was 80 days (Figure 2.3). No significant difference in longevity was detected between the sexes. Beach mice lived significantly longer at FMNM compared to ASRA (Mann-Whitney, Z = 85.1, P = 0.0001). Mean survivorship differed among age classes at both ASRA (Kruskal-Wallis X^2 = 163.4, P = 0.0001, df = 2) and FMNM (Kruskal-Wallis X^2 = 33.9, P = 0.0001, df = 2), with mice initially captured as adults living longer than those initially captured as either subadults or juveniles.

The number of mice surviving between seasons expressed as a proportion of the total number of mice captured was used to examine seasonal patterns of survival (Table 2.2). Survivorship at FMNM was significantly greater than at ASRA throughout 1989, April-July 1990, and October 1990-January 1991 (2-sample proportion test, $P < 0.05$). Survivorship decreased at both ASRA and FMNM from April through October 1989, followed by a significant increase from October 1989 to January 1990 at both sites (2-sample proportion test, ASRA: $P < 0.001$, FMNM: $P < 0.05$).

Although the general trends in survivorship were similar between the Jolly-Seber and enumeration methods, these two estimates did not correlate well (ASRA, Pearson $r = 0.6347$, $P < 0.05$; FMNM Pearson $r = 0.252$, $P < 0.05$). The Jolly-Seber survival estimates provided an estimate of variance for each estimate, which the enumeration estimates did not (Table 2.2).

Sex Ratio

The sex ratio (all age classes, grids pooled) at FMNM did not differ significantly from 1:1 in any trapping session, whereas sex ratios at ASRA (all age classes, grids pooled) deviated significantly from 1:1 only in January 1990 ($X^2 = 4.32$, $P < 0.05$, $DF = 1$), when more males than females were present. Adult sex ratios did not differ from 1:1 in any instance, but sex ratios for immature individuals (subadults and juveniles) deviated from 1 at both ASRA ($X^2 = 4.67$, $P < 0.05$, $DF = 1$) and FMNM ($X^2 = 6.37$, $P < 0.05$, $DF = 1$) in July 1990; more females than males were present in both cases.

Age Structure

The ASRA population was composed of a large proportion of immature individuals, except during the April 1990 trapping session (Figure 2.4). This result was consistent with the occurrence of year-round reproduction in the ASRA population. In contrast, age composition of the FMNM population changed seasonally, with immature individuals comprising a small proportion of the population in January-April of 1989 and April 1990. Both the ASRA and FMNM populations contained significantly more adults than immature beach mice in all trapping sessions (X^2, $P < 0.05$, $DF = 1$).

Reproduction

While the ASRA population generally had a greater proportion of adults in breeding condition than the FMNM population, overall patterns of reproductive activity were similar (Figures 2.5 and 2.6). Significant differences between ASRA and FMNM in the proportion of adults in breeding condition occurred in January 1989, January 1990, October 1990, and January 1991 (2-sample proportion test, $\underline{P} < 0.01$). Reproductive activity was low in January and April, and activity increased in July and decreased in October. The increase in reproductive activity from April to July in 1989 and 1990 was significant at both study areas (two sample proportion test, $\underline{P} < 0.05$).

Between 80 and 85% of mice captured from April 1989 through January 1990 were new recruits at ASRA, indicating year-round reproduction and high turnover rates in that population (Figure 2.7). In contrast, recruitment at FMNM was more seasonal. Less than 20% of mice captured at FMNM in April 1989 were new recruits, and the proportion of new recruits increased steadily in 1989 to 80% by January 1990. The proportion of recruits differed between ASRA and FMNM in April and July 1989 (2-sample proportion test, $\underline{P} < 0.05$). Following peak population densities in January 1990 at both ASRA and FMNM, recruitment levels in April 1990 were relatively low at both sites (ASRA: 51%, FMNM: 18%). Following the low population numbers in April 1990, the percentage of new recruits in the populations gradually increased through 1990 to 83% at ASRA and 62% at FMNM in January 1991.

Body Mass

Excluding pregnant females, mean body mass of adult beach mice from ASRA (overall mean = 14.0 ± 0.1 g) was significantly greater than mice from FMNM (overall mean = 13.2 ± 0.1 g) in every month except April 1989 and October 1990 (Figure 2.8, $P < 0.05$). Adult mice in reproductive condition were significantly heavier than mice in non-reproductive condition (males: $P < 0.001$, females: $P < 0.001$).

Pooling data over all seasons, grids and study sites, the overall mean body mass was 15.0 ± 0.1 g for adult male mice and 14.8 ± 0.1 g for adult non-pregnant female mice; these means were statistically similar. Comparing sexes separately, mean body mass differed during October 1989 and July 1990 through January 1991 at FMNM ($P < 0.05$), whereas mean body mass differed only in July 1990 at ASRA ($P < 0.05$). Neither sex was consistently heavier at either study site.

Interactions with Domestic Cats and House Mice

Domestic cats. Because cats were never recorded on the grids at FMNM, the data reported are for the ASRA grids only. Cats were common on the grids at ASRA during the winter and spring of 1989, and at least some cat activity was recorded throughout the entire study (Figure 2.9). Concurrent with this study, the Florida Department of Environmental Protection (FDEP) initiated a cat control program at ASRA. The removal of cats from ASRA was begun in the fall of 1989, and approximately 25 cats were removed through the fall. Cat control was continued throughout the study by the FDEP.

Concurrent with the efforts to control cats at ASRA, a reduction in cat track abundance on the grids was observed (Figure 2.9). Beach mouse populations at ASRA, previously at very low numbers, showed an abrupt increase beginning in January 1990 (Figure 2.9). Although not carefully controlled or replicated, these patterns suggest an inverse relationship between cat abundance and beach mouse population levels.

House mice. House mice (Mus musculus) were recorded only on grids at ASRA, and were always at low population levels relative to beach mice (Figure 2.10). Only during January 1990 were any appreciable numbers of house mice recorded, and this was during a period of peak beach mouse populations (Figure 2.10). Sporadic trapping conducted in and around refuse containers on the beach captured only beach mice, suggesting that house mice were not utilizing this resource. No pattern in house mouse distribution towards residential areas at the southern end of ASRA was apparent. House mice at ASRA appear to live a low-density feral existence.

Discussion

Population Levels

Peromyscus polionotus populations generally exhibit more seasonal and annual variation than other species in the genus (Terman 1968), and beach mouse populations are especially characterized by large seasonal fluctuations (Blair 1951, Kiem 1979, Extine 1980, Rave and Holler 1992). The results of this study further illustrate this variation, and also illustrate the extreme variability in population levels within a relatively small geographic area.

The ASRA and FMNM study areas are separated by a distance of approximately 14 km and are similar in structure and vegetation. Despite this proximity, the populations at these sites differed markedly in annual population fluctuations, survivorship, recruitment patterns, and age structure, especially during the first year of the study. For example, population estimates as low as two individuals per ha in January 1989 were recorded at ASRA while comparative population estimates at FMNM were 25-29 individuals per ha. Population estimates in January 1991 of 90 mice per ha were recorded at ASRA while the corresponding population estimate at FMNM was 15 mice per ha.

Population dynamics of the Anastasia Island beach mouse were similar to that recorded for the southeastern beach mouse (P. p. niviventris) on Merritt Island, Florida (Stout 1979, Kiem 1979, Extine 1980, Extine and Stout 1987), the subspecies geographically closest to P. p. phasma and occupying a similar habitat. P. p. niviventris populations fluctuated between years, ranging from seven per ha in summer 1977 to 59.7 per ha in winter 1979.

A seasonal pattern in population fluctuation was not discernable in this study, probably as a result of high variability in population levels within the population and the short duration of the study. Population peaks were observed during winter 1990 at both ASRA and FMNM and again in winter 1991 at ASRA, suggesting a pattern of high winter populations. However, population lows at ASRA during winter 1989 and at FMNM during winter 1991 deny this suggestion and further illustrate the extreme variability in population fluctuations of this beach mouse. Similarly, Rave and Holler (1992) were unable to establish clear patterns of seasonal population fluctuations, although they too reported a tendency for high winter populations.

Blair (1951) recorded maximum densities of Santa Rosa Island beach mice (P. p. leucocephalus) of 3.5 per ha in December and minimum densities of 2.0 per ha in November in northwestern Florida. Rand and Host (1942) estimated 21 oldfield mice per ha at an inland location in south-central Florida based on burrow excavation, and Smith (1968) estimated 173.8 per ha in north-central Florida based on a combination of burrow excavation and trapping. In that study, the trap-revealed density was 39.3 per ha, and the remaining 134.5 per ha were lactating females and immatures located in the burrows and not a part of the trappable population (Smith 1968). In South Carolina, Davenport (1964) described one annual cycle for oldfield mice, with peak spring densities of 21.2 oldfield mice per ha declining to a midwinter low of 4.2 per ha. Caldwell (1964) described three distinct annual patterns of abundance for oldfield mice in South Carolina on grids located in close proximity to one another, further illustrating the variability in population dynamics exhibited by this species.

Population Estimation

Program CAPTURE is based on several assumptions including population closure, high capture probabilities of individual animals, and adequate sample sizes. Failure to meet these assumptions can result in biased estimates (Menkens and Anderson 1988). Data in this study were adequate for use with program CAPTURE in most cases. Population closure was not rejected in 49 of 58 cases (85%), and capture probabilities in this study were typically high, ranging between 0.40 and 0.81. Cases of small sample sizes (< 20 individuals being captured) were common (24 of 58 cases, 41%), although capture probabilities in these instances were typically high (mean=0.56, range 0.22-0.83). CAPTURE population estimates obtained at low population sizes (< 20) may be biased with an unknown variance and should be interpreted cautiously.

CAPTURE contains eight models for estimating population size, and model selection is based on the specific characteristics of each data set. Model selection for this study was highly variable, reflecting both the variation in trap response over time and space, and possibly errors inherent in the CAPTURE model selection procedure (Menkens and Anderson 1988, White et al. 1982). There was an obvious tendency for the NULL model to be selected at low population sizes (61% for $N < 20$, 16% for $N > 20$) because the limited data precluded adequate testing of alternative models. As a result, CAPTURE population estimates for small samples are probably biased with an underestimate of the true variance (White et al. 1982). However, the high degree of correlation between CAPTURE estimates and simple enumeration ($r=0.98$) indicate that both methods are reliable for estimating beach mouse population size.

Survival

The survivorship curve for beach mice resembled Deevey's type III (Deevey 1947), with a relatively small proportion of the population surviving long periods of time. Estimates of longevity from this study were generally comparable to that recorded for beach mice in other locations. Dapson (1979) reported the mean ages of adult female P. p. phasma collected at the ASRA location to range from 71-304 days using an aging technique that assayed the insoluble fraction of eye lens protein. Rave and Holler (1992) reported mean survival from initial capture to be 120 days, with 21 individuals surviving 12-20 months. Kiem (1979) reported that the majority of individual Southeastern beach mice lived 124 days or less, but that a limited number survived as long as 434 days. Extine (1980) reported the average residency of beach mice to be 87 days for all mice captured, and 109 days for mice captured more than one time.

The significant difference in mean survivorship between the ASRA and FMNM populations observed in this study was probably a function of the higher production in the ASRA population, especially from January 1990 through January 1991. The greater productivity of the ASRA site would tend to lower the mean age of mice compared to the more less dense, more stable FMNM population. However, this difference could also be a function of differential predation or habitat differences between the sites. On Merritt Island, Extine (1980) reported lower survivorship of P. p. niviventris living in dune scrub compared to a beach dunes. Rave and Holler (1992) did not report differences in mean beach mouse survival between their two primary study sites.

Interactions with House Cats

Data from this study suggest that predation by house cats on Anastasia Island is an important factor affecting beach mouse populations. These small, efficient predators occur in large numbers on Anastasia Island and were common in the dunes at ASRA throughout the first year of the study. Supplemental feeding by pet owners, campers at

ASRA, beach residents, and oceanside restaurants may artificially increase cat densities in dune habitats. Removal of cats at ASRA following the first year of the study appears to have allowed beach mouse populations to increase to high densities and restored several ecological parameters to levels comparable with FMNM, where cats were absent. However, because the cat removal at ASRA was neither closely controlled or replicated, conclusions regarding the role of cats in structuring beach mouse populations remain speculative.

Feral cats are the most widespread terrestrial carnivore on earth, and the fact that feral cats negatively affect a vast array of wildlife species, especially birds and small mammals, is well documented (McMurry and Sperry 1941, Pearson 1964, Iverson 1978). Cats are extremely flexible in food habits and social organization (Jones and Coleman 1981, Liberg 1984, Konecny 1987) and hunt even when fed daily by humans (Warner 1985, Churcher and Lawton 1989). Studies of food habits of feral cats have shown that mice often compose a large proportion of the diet (Jones and Coleman 1981, Churcher and Lawton 1989). Blair (1951) considered predation to be the single most important factor affecting beach mouse survival and several authors consider house cats a serious threat to beach mouse populations (Bowen 1968, Ehrhart 1978, Humphrey and Barbour 1981, Holliman 1983). Bowen (1968) found cats on Santa Rosa Island to be such an important factor in the reduction of beach mouse populations that he avoided trapping in areas with cat sign and further suggested that stretches of beach with unusually high levels of cat predation may serve as barriers to gene flow. The pallid beach mouse (P. p. decoloratus) is extinct (Humphrey and Barbour 1981), and extensive sampling in 1989 at the type locality for the subspecies revealed extremely high densities of feral cats (personal observation).

Interactions with House Mice

P. polionotus and M. musculus are similar in size, exhibit overlapping food habits, and commonly occupy the same habitat (Gentry 1966) . This ecological similarity suggests competition for resources such as food and homesites or interference competition in the form of inter-specific aggression may occur between these species. The Mus population in the more intact habitats at ASRA and FMNM was minimal compared to the beach mouse populations at those locations. In contrast, Mus were more abundant in the developed habitat on Anastasia Island than in the relatively undisturbed habitat at ASRA and FMNM, although beach mice were also more abundant in these areas (Chapter 3).

These patterns suggest that in the relatively intact ecosystems at ASRA and FMNM, Mus is prevented from establishing persistent populations either through inadequate habitat requirements or possibly competitive interactions with the relatively dense beach mouse populations at these sites. However, where habitat conditions are degraded by development, Mus may have a competitive advantage and is able to establish populations in the dune habitats. On Anastasia Island, Mus may pose a threat to beach mouse populations in urbanized areas where the dune habitats are highly disturbed but are probably not threatening beach mouse populations at more intact habitats at ASRA and FMNM.

Several authors have reported an inverse relationship between the population densities of Mus and P. polionotus (Caldwell 1964, Caldwell and Gentry 1965, Gentry 1966). These studies have concluded that Mus is a poor competitor with P. polionotus under conditions optimal for P. polionotus, and may be capable of coexisting with P. polionotus through migratory behavior (Caldwell 1964, Caldwell and Gentry 1965, Gentry 1966). Briese and Smith (1973) concluded that Mus primarily invades disturbed areas or areas where human structures provide suitable places to live, but the two species seldom coexist in undisturbed natural habitats. Humphrey and Barbour (1981) documented mutually exclusive distribution patterns of Gulf coast beach mice and Mus and suggested these patterns were a result of competitive exclusion of beach mice by Mus following habitat degradation and the introduction of exotic predators. King (1957) studied aggressive behavior of Mus and Peromyscus leucopus and suggested that these species might aggressively compete in nature. However, Caldwell (1964) found no evidence of direct aggressive competition between Mus and P. polionotus under field or laboratory conditions, and they even observed these species to share common nests under laboratory conditions.

Under feral conditions, Mus populations are ephemeral and migratory, and surplus house mice tend to emigrate before dense populations are established (Caldwell 1964, Caldwell and Gentry 1965). House mice are inferior competitors with native P. polionotus under conditions optimal for P. polionotus and the migratory adaptation allows Mus to avoid competition with native species by colonization of available habitats (Caldwell 1964, Caldwell and Gentry 1965). In studies where populations of both species were confined and Mus unable to emigrate, Mus was unable to persist in the presence of P. polionotus (Caldwell 1964, Caldwell and Gentry 1965). Gentry (1966) extended this conclusion to include unconfined situations.

House mice are able to establish themselves in disturbed habitats occupied by low densities of P. polionotus, but are excluded when densities are high (Briese and Smith 1973). Additionally, the presence of human habitations which serve as sources of colonization for house mice improve their ability to colonize adjacent habitats. Factors such as food shortages (Gentry 1966), predation by exotic feral cats, and habitat degredation (Bowen 1968, this study) can depress P. polionotus populations allowing colonization of Mus, and house mouse populations do not seem to be as seriously affected by house cat predation as P. polionotus (Briese and Smith 1973).

In the present study, Mus was present in low numbers on the grids at ASRA during a period of low beach mouse density (1989), but following a period of peak beach mouse numbers in January 1990, Mus numbers decreased and were eventually absent from ASRA. Mus exhibited a broad distribution over Anastasia Island during the summers of 1989 and 1990 in habitat adjacent to development, but was generally quite uncommon wherever it was encountered (Chapter 3). Mus did not appear to depend on refuse storage containers as was previously suspected, but instead were feral in dune habitats. Following local extinctions at ASRA, Mus may recolonize dune habitats from the either the adjacent residential neighborhoods or the town of St. Augustine Beach.

Table 2.1. Number of individuals captured (M), total number of captures (n), capture probability (P), population estimate (N ± S.E.), and 95% confidence intervals (C.I.) from the program CAPTURE, for beach mice on Anastasia Island. Models with an ! failed to meet the assumption of closure. Models TH and BH do not provide an estimate of overall capture probability.

Grid	Season	M	n	P	Model	N (S.E.)	95% C.I.
AI 1	Winter '89	11	21		TH !	13 ± 4.2	11-34
	Spring '89	20	53		BH	21 ± 1.9	20-31
	Summer '89	15	35		BH	16 ± 1.9	15-27
	Fall '89	10	24	0.6	NULL	10 ± 0.6	10-10
	Winter '90	69	166		BH	88 ± 12.3	74-129
	Spring '90	59	188	0.8	NULL	59 ± 0.3	59-59
	Summer '90	43	110	0.58	H	46 ± 3.3	43-59
	Fall '90	31	71	0.4	B	35 ± 4.3	31-53
	Winter '91	90	239	0.59	H !	100 ± 4.8	94-114
AI 2	Winter '89	5	12		TH	7 ± 2.8	5-19
	Spring '89	8	26		TH	8 ± 0.7	8-12
	Summer '89	15	40	0.67	NULL	15 ± 0.5	15-15
	Fall '89	11	27	0.61	NULL	11 ± 0.5	11-11
	Winter '90	48	109	0.22	B !	75 ± 23.4	54-165
	Spring '90	50	145	0.72	NULL	50 ± 0.5	50-50
	Summer '90	36	97	0.62	H	38 ± 3.1	36-52
	Fall '90	31	63		BH	46 ± 15.8	33-112
AI 3	Winter '89	2	5	0.62	NULL	2 ± 0.2	2-2
	Spring '89	8	21		TH	8 ± 1.3	8-16
	Summer '89	15	43		BH !	16 ± 1.9	15-27
	Fall '89	12	25	0.45	NULL	13 ± 1.3	12-19
	Winter '90	44	110	0.32	B	55 ± 8.9	46-88
	Spring '90	32	77	0.32	B !	40 ± 7.8	33-72
	Summer '90	29	58	0.47	NULL	31 ± 2.0	29-39
	Fall '90	43	102	0.58	H	44 ± 1.3	43-49
	Winter '91	73	160	0.28	B	96 ± 16.6	78-152

Table 2.1--continued.

Grid	Season	M	n	P	Model	N (S.E.)	95% C.I.
AI 4	Winter '89	6	17	0.83	TH	7 ± 1.8	6-15
	Spring '89	15	39	0.65	NULL	15 ± 0.5	15-15
	Summer '89	15	33	0.55	NULL	15 ± 0.9	15-15
	Fall '89	14	29		TH	25 ± 8.6	17-56
	Winter '90	51	131	0.29	B !	67 ± 12.6	55-113
	Spring '90	37	104	0.67	H	38 ± 2.9	37-52
	Summer '90	38	83	0.52	NULL	40 ± 1.7	38-46
	Fall '90	48	118	0.53	H	54 ± 4.1	50-68
AI 5	Summer '89	13	23	0.4	NULL	14 ± 1.9	13-24
	Fall '89	9	17	0.46	NULL	9 ± 1.1	9-9
	Winter '90	39	107	0.69	H !	43 ± 3.6	40-56
	Spring '90	47	118	0.52	H	57 ± 5.6	50-74
	Summer '90	38	81	0.36	H	56 ± 7.6	46-77
	Fall '90	74	186	0.55	H	84 ± 4.9	78-99
FM 1	Winter '89	25	69	0.49	B	26 ± 2.2	25-37
	Spring '89	23	71	0.77	NULL !	23 ± 0.2	23-23
	Summer '89	15	42	0.7	NULL	15 ± 0.4	15-15
	Fall '89	14	28	0.48	NULL	15 ± 1.3	14-20
	Winter '90	47	123	0.56	H	54 ± 4.6	49-69
	Spring '90	24	65	0.68	H !	24 ± 2.3	24-40
	Summer '90	32	91	0.71	H	32 ± 2.3	32-48
	Fall '90	21	54	0.43	H	30 ± 4.9	24-45
	Winter '91	19	54	0.71	NULL	19 ± 0.4	19-19
FM 2	Winter '89	29	85	0.57	B	30 ± 1.4	29-37
	Spring '89	24	67	0.7	B	24 ± 0.5	24-24
	Summer '89	16	44	0.69	NULL	16 ± 0.4	16-16
	Fall '89	15	27		TH	21 ± 6.7	16-49
	Winter '90	41	120	0.73	H	43 ± 2.9	41-56
	Spring '90	20	58	0.7	NULL	21 ± 0.4	21-21

Table 2.1--continued.

Grid	Season	M	n	P	Model	N (S.E.)	95% C.I.
	Summer '90	23	52	0.42	H	30 ± 4.6	25-45
	Fall '90	11	26	0.59	NULL	11 ± 0.6	11-11
	Winter '91	15	41	0.68	NULL	15 ± 0.4	15-15

Table 2.2. Simple enumeration (ϕ) and Jolly-Seber (ϕ') survival estimates for Anastasia Island beach mice. R_i is the number of individuals captured in period I, r_i is the number of R_i recaptured in period I+1, and ϕ and ϕ' are the survival rates between I and (I + 1).

Site	Period	R_i	r_i	ϕ	ϕ'
ASRA	WINTER -SPRING '89	28	8	0.29	0.15 ± 0.08
ASRA	SPRING -SUMMER '89	53	13	0.24	0.35 ± 0.18
ASRA	SUMMER -FALL '89	77	12	0.16	0.18 ± 0.07
ASRA	FALL '89 -WINTER '90	58	31	0.53	0.42 ± 0.09
ASRA	WINTER -SPRING '90	251	108	0.43	0.46 ± 0.04
ASRA	SPRING -SUMMER '90	223	78	0.35	0.30 ± 0.04
ASRA	SUMMER -FALL '90	180	51	0.28	0.26 ± 0.09
ASRA	FALL '90 -WINTER '91	164	27	0.16	0.21 ± 0.15
FMN	WINTER -SPRING '89	53	38	0.72	0.54 ± 0.17
FMN	SPRING -SUMMER '89	45	21	0.47	0.25 ± 0.10
FMN	SUMMER -FALL '89	31	10	0.32	0.44 ± 0.23
FMN	FALL '89 -WINTER '90	29	17	0.59	0.38 ± 0.13
FMN	WINTER -SPRING '90	87	37	0.42	0.59 ± 0.11
FMN	SPRING -SUMMER '90	45	24	0.53	0.34 ± 0.10
FMN	SUMMER -FALL '90	54	16	0.30	0.30 ± 0.09
FMN	FALL -WINTER '91	31	13	0.42	0.31 ± 0.13

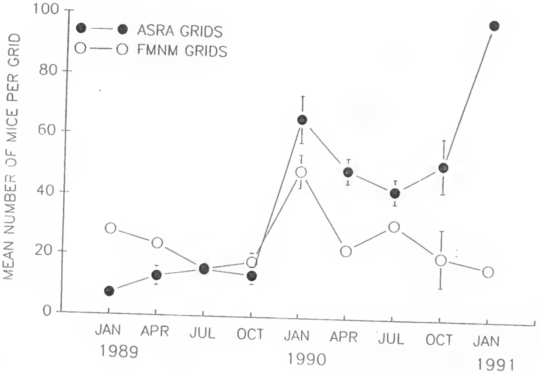

Figure 2.1. Mean number of beach mice captured per 1-ha trapping grid estimated by the minimum number known alive (MKA) at FMNM and ASRA. Five grids were trapped at ASRA, except that 4 grids were trapped in January-April 1989 and 2 grids were trapped during January 1991. Two grids were trapped at FMNM throughout the study.

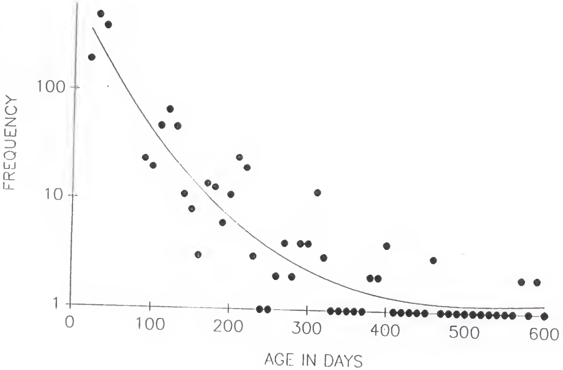

Figure 2.2. Frequency plot of known age in days for all Anastasia Island beach mice recaptured between at least two or more trapping sessions.

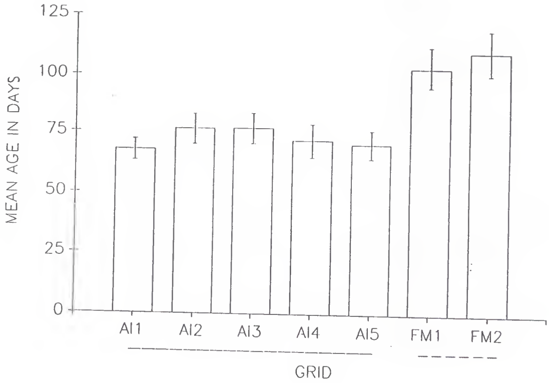

Figure 2.3. Mean age in days of beach mice based on recaptures of marked individuals on trapping grids at ASRA and FMNM. Grids with labels joined below by lines do not differ significantly in age (α=0.05).

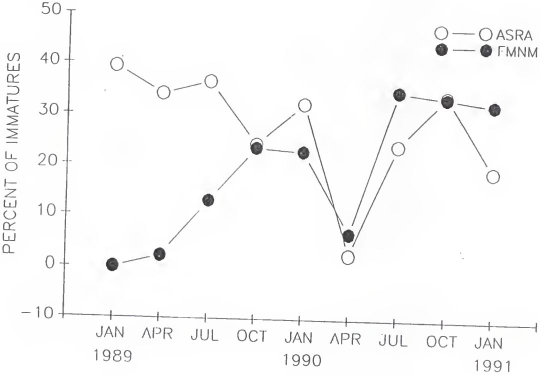

Figure 2.4. Age structure of beach mice as the percent of immatures (juvenile or subadult) out of the total individuals captured on grids at ASRA and FMNM.

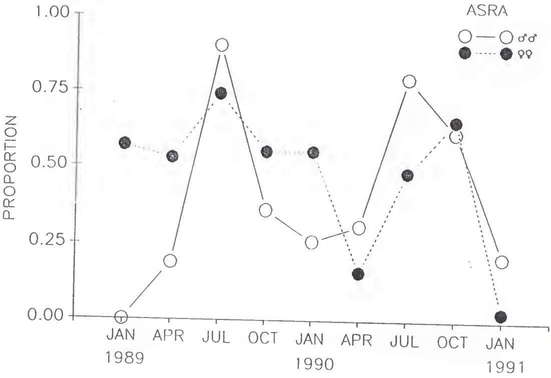

Figure 2.5. Proportion of adult beach mice captured on grids at ASRA in reproductive condition as determined by external reproductive characters.

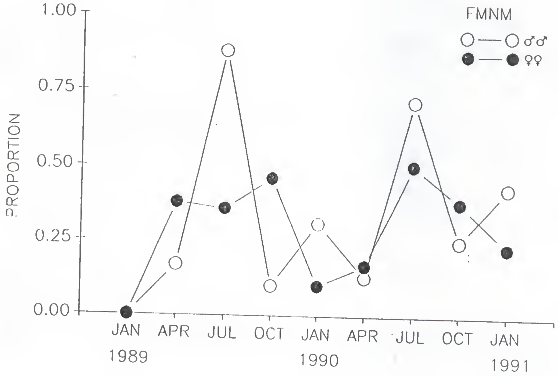

Figure 2.6. Proportion of adult beach mice captured on grids at FMNM in reproductive condition as determined by external reproductive characters.

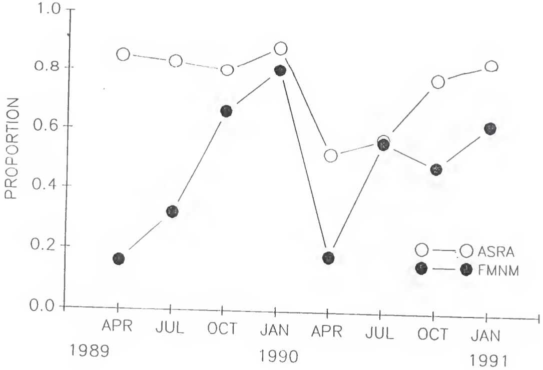

Figure 2.7. Recruitment as measured by the proportion of first captures of beach mice on grids at ASRA and FMNM.

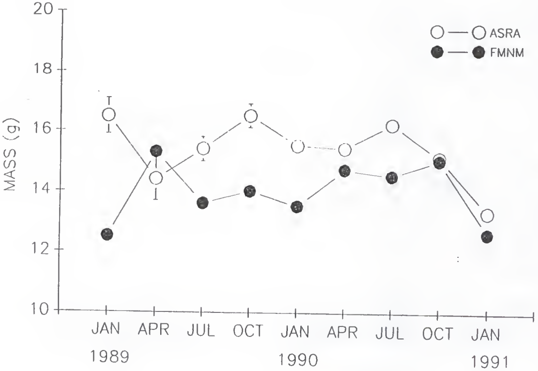

Figure 2.8. Adult body mass (excluding reproductively active females) of beach mice captured on grids at ASRA and FMNM.

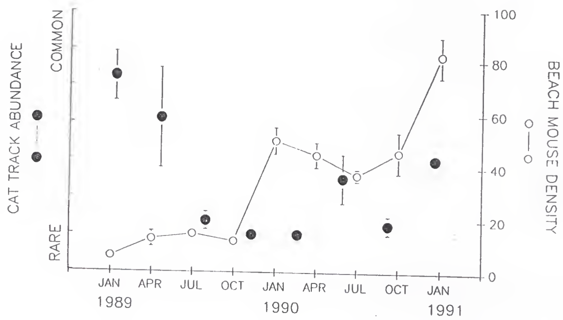

Figure 2.9. Domestic cat abundance on 1-ha trapping grids at ASRA as indexed by track counts conducted during each trapping session. Beach mouse density at ASRA (mean number of beach mice per grid) is presented for comparison.

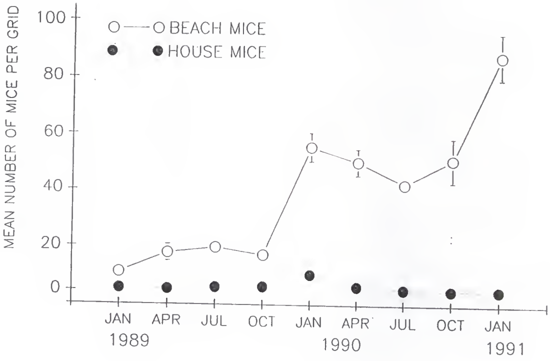

Figure 2.10. House mouse and beach mouse abundance on 1-ha trapping grids at ASRA. Population size was estimated using the minimum number known alive (MKA). No house mice were captured during April 1989, October 1990, and January 1991.

CHAPTER 3
DISTRIBUTION AND HABITAT

Introduction

Preservation of the Anastasia Island beach mouse will require the obvious: preservation of suitable habitat. However, the Anastasia Island beach mouse is atypical of many of Florida's rare species in that opportunities to preserve habitat through acquisition and restoration programs no longer exist. Whereas acquisition of privately-owned habitat is often the primary conservation action needed for many endangered species, the oceanfront dune habitats that support the Anastasia Island beach mouse are mostly either developed or already under public ownership. Thus, the challenge in preserving the Anastasia Island beach mouse lies not in the strategic design of preserves, buffers, and corridors but in careful management of the populations remaining on a few fragile remnants of suitable habitat.

That beach mice occupy beach dune habitats is well understood. However, details on the specific habitat requirements and use of different vegetation zones by Anastasia Island beach mice has not been examined. Detailed studies on habitat use by other subspecies include those by Blair (1951) on the Santa Rosa beach mouse (P. p. leucocephalus), Kiem (1979) and Extine (1980) on the southeastern beach mouse (P. p. niviventris), and Meyers (1983) on three Gulf coast subspecies. Habitat requirements of P. p. phasma remain unstudied. In addition, because much of the original habitat of the Anastasia Island beach mouse has been lost as a result of development, an assessment of the extent and condition of the remaining habitat is needed.

The goal of this study is to determine the island-wide distribution and specific patterns of habitat use of beach mice and other sympatric small mammals on Anastasia Island and to determine the amount of suitable habitat that remains. This information is required to understand how habitat loss and further habitat degradation will affect this endangered beach mouse population.

Methods

The habitat on Anastasia Island can be divided into three ownership areas: Anastasia State Recreation Area (ASRA), Fort Matanzas National Monument (FMNM), and privately-owned property (Figure 1.1). ASRA is located at the northern end of the island, is managed by the State of Florida (FDEP), and includes approximately 6.0 km of continuous dunes. The dunes at ASRA mostly occur on a narrow peninsula known locally as Conch Island that was formed as a result of the relocation of the St. Augustine Inlet in the early 1940s. As a result, the topography of Conch Island differs from the rest of Anastasia Island; a stable dune zone is entirely absent and the transition zone is extremely wide and adjoins salt marsh to the west. FMNM is located at the southern end of the Anastasia Island, has 2.9 km of continuous dunes, and is managed by the National Park Service. Vegetation at ASRA and FMNM is generally similar with the exception that the transition zone at FMNM has a greater abundance of woody species, shrubs, and dense swales than at ASRA and the transition zone at FMNM borders stable dunes vegetated by oak forest to the west. The remainder of the habitat on the island consists of a strip of privately-owned property between ASRA and FMNM, adjacent to residential and commercial development.

Potential beach mouse habitat occurs along the length of Anastasia Island with the exception of an area extending from ASRA southward for about 300 m where the foredunes and transition zone have been completely obliterated and replaced with a concrete revetment. This area creates an effective barrier against beach mouse movement between ASRA and the rest of the island. The beach mouse population on Anastasia Island is fragmented into two major regions: ASRA and the remainder of the island including FMNM and the narrow strip of habitat adjacent to the developed portions of the island (Figure 1.1)

The distribution of beach mice along the length of the island was determined by transect trapping in foredune vegetation using 100-m transects with ten stations at 10-m intervals and oriented parallel to the beach. A single Sherman small mammal trap was placed at each station, baited with rolled oats and peanut butter and trapped for four consecutive nights each. A series of 31 transects was trapped during July 1989 and a subset of 15 of these was trapped again during July 1990 for a total of 1,840 unadjusted trap nights. In habitat adjacent to development, trap stations were usually between 25-75 m from houses or condominiums. Spacing between transects varied depending on the terrain but was generally between 0.5 and 1.0 km.

To determine detailed patterns of habitat use, a series of transects was established in foredune (N=10), transition (N=10), and stable dune habitats (N=3) at FMNM and ASRA. The configuration of the transects was designed to cover the entire range of potential beach mouse habitats from foredune to stable dune habitats. These transects were trapped quarterly for one full year.

Vegetative composition and structure were analyzed within a 5 m radius of each trap station in foredune (N=100), transition zone (N=100), and stable dune habitats (N=30) during the summer and fall of 1991 (Table 3.1). Methodology for measuring habitat variables was adapted from Hays, Summers, and Seitz (1981) and Bonham (1988). Measurements for each variable were taken in each of four quarters at each station determined randomly by spinning a cross with quarters marked on it. Percent ground cover (a measure of amount of exposed soil) and tree canopy cover were visually estimated in each quarter using cover classifications (0%, 1-20%, 21-40%, 41-60%, 61-80%, 81-99%, 100%, Bonham 1988). A 1.0 m^2 rectangular quadrat made of 1.8 cm PVC pipe and randomly located in each quarter by a random toss was used to measure ground cover, number of herbaceous species, and sea oat density. Horizontal vegetation structure was visually estimated with a 1.0 m vegetation density board partitioned into 0.25 m sections and viewed at a distance of 5.0 m (Nudds 1977). Distance to beach was measured to the seaward toe of the primary dune from aerial photographs.

Trapping sessions on the transects were conducted quarterly over a period of one year; April 1989, July 1989, October 1989, and April 1990. Trapping sessions lasted four consecutive nights and were conducted regardless of weather conditions. Traps were provided with cotton for insulation during cool weather to protect animals from exposure. A single Sherman small mammal trap baited with a mixture of rolled oats and peanut butter was set at each trap station in the afternoon and checked and closed the following morning. Traps were cleaned thoroughly following each trapping session. Data collected on rodents included location of capture, species, sex, age, mass, and reproductive condition.

Habitat variables were transformed with log (x +1) transformation and analyzed using one-way analysis of variance with fixed effects and unequal sample sizes for treatments, and those variables that were not significantly different were dropped from further analysis. Multivariate statistics were then used to characterize the habitats and further understand the relative importance of each variable. Discriminant functions were used to determine the error associated with the subjective classification of habitat zones compared to statistical groupings of the raw data. To further examine the variation between zones, data classified by zone were subjected to principal components analysis. Factor analysis was conducted on the first five principal components in order to determine the contribution of each of the original habitat variables to the uncorrelated factors of the original variables.

Relative use of vegetation zones by individual rodent species was examined using chi-square analysis. Statistical relationships between individual rodent species captures within each habitat zone were established using a Spearman correlation matrix of rodent species captures with the first five principal components. Significant correlations indicated either positive or negative associations of individual species with principal components describing features of the vegetation.

Results

Island-wide Distribution of Rodent Species

Beach mice were captured at every site (N=31) sampled during July 1989 and 13 of the 15 sites sampled during July 1990 (Table 3.2). Overall, 5.89 and 5.39 beach mice captures per 100 trap nights were recorded in 1989 and 1990 respectively, with the number of individuals captured per transect ranging from 1 to 5. House mice were captured at 9 of the 31 sites in 1989 and 7 of the 15 sites in 1990, with an overall capture success (captures per 100 trap nights) of 0.89 in 1989 and 3.0 in 1990.

Beach mice and house mice were captured on the same transect in nine of 31 transects in 1989; no transects captured exclusively house mice. In 1990, beach mice and house mice co-occurred on the same transect in five of the 15 transects and house mice alone were captured on two transects, although one of these was in extremely degraded habitat judged unsuitable for beach mice.

To compare beach mouse density in disturbed habitat adjacent to development to the relatively undisturbed habitats on public property, data from a series of eight foredune transects trapped at FMNM during July 1989 and July 1990 using identical methodology were summarized for comparison. Beach mouse densities remained stable from 1989 to 1990 in the developed habitat, but were much reduced relative to densities in undisturbed habitats at FMNM (Table 3.2). This difference was significant during both 1989 (Mann-Whitney U = 31.0, $\underline{P} = 0.001$) and 1990 (Mann-Whitney U = 23.5, $\underline{P} = 0.01$). House mice were completely absent from the undisturbed FMNM transects (Table 3.2).

Habitat Use by Rodent Species

Three distinct zones of vegetation, differing in both species composition and structural complexity, are available to beach mice on Anastasia Island (Table 3.3). Stable dune vegetation is characterized by dense canopy cover, little exposed soil, relatively dense understory vegetation, low herbaceous species richness, and most distant from the beach. Transition zone vegetation is characterized by an absence of overstory vegetation, extensive exposed soil, relatively low horizontal vegetation density, high herbaceous species richness, low density of sea oats, and an intermediate distance from the beach. Foredune vegetation is typically sparse with no canopy coverage, exposed soil, relatively few herbaceous species, a high density of sea oats, and is adjacent to the beach.

Vegetation zone classification using discriminant functions was generally accurate, with the only mis-classification errors occurring between foredune and transition zones (Table 3.4). The foredune and transition zones intergrade to a greater degree than transition zone and stable dunes.

Greater than 95% of the variation in the vegetation data was accounted for by the first five principal components (Table 3.5). A plot of the first two principal components show considerable separation between zones along the two axes, with the most overlap occurring between foredune and transition zones (Figure 3.1). The factor analysis indicates high loadings on factor 1 for canopy cover and distance to beach, suggesting this factor differentiates stable dune vegetation from other vegetation types (Table 3.5). Factor 2 has high loadings for sea oat density and number of herbaceous species, variables differentiating foredune vegetation from the other vegetation zones.

Rodent captures were not distributed equally among habitat types (Table 3.6). Of the 474 beach mouse captures on the habitat transects, the majority were in foredunes, with the remainder in transition zone habitat. Cotton rats (Sigmodon hispidus) were commonly captured in all three zones, but were most abundant in stable dunes. Black rats (Rattus rattus) were captured primarily in stable dunes, and all Mus captures were in foredunes.

A correlation matrix between rodent captures and the principal components further illustrates the above pattern. Beach mouse captures were significantly correlated with PC 2, a component differentiating foredune from the other habitat types. A significant negative correlation between beach mouse captures and PC 1, the component distinguishing stable dunes, illustrates the paucity of beach mouse captures in stable dune vegetation (Table 3.7). There was a significant positive correlation with both cotton rat and black rat captures and PC 1, indicating the high use of stable dune vegetation by these species. House mouse captures were too few for reliable correlations.

The conclusion of the above analysis suggests that beach mice prefer foredunes but also occur commonly in the transition zone. Cotton rats occur in all habitat types with approximately equal frequency, black rats were captured primarily in the stable dunes, and house mice preferred the foredunes.

Discussion

Beach Mouse Habitat Use

Beach mice in this study used open, sandy habitats and were not found in excessively dense vegetation or habitats with a well-developed overstory. Although a wide range of microhabitat types was used, primary and sparse transitional dune vegetation was clearly selected. This information is consistent with previous information on habitat use by this subspecies. Ivey (1949) found beach mice in most of the more open dune habitats north of St. Augustine inlet, especially the bare sand and sea oat communities occupying the dunes nearest the ocean. He failed to capture any individuals in damp, grassy areas or stable dunes covered with hammock. Pournelle and Barrington (1953) captured beach mice on Anastasia Island in open dunes and scrubby vegetation within 600 m of the primary dune.

Work on other subspecies of beach mice have found similar patterns of habitat use. Meyers (1983) found optimal beach mouse habitat was characterized by maximum site elevation and elevational differences, proximity of forest to beach, sparse shrub presence, moderate number of herbaceous species and low cover values of sea oats, although none of these variables alone were particularly strong predictors of beach mouse habitat. He also concluded that the presence of nearby (1.0-2.0 km) low density housing does not affect beach mouse populations as long as optimal habitat is available. Blair (1951) found beach mice occurring in a wide variety of microhabitats across the entire width of Santa Rosa Island but noted concentrations of mice towards the beach in foredune habitats. Beach mice on Merritt Island occupy a variety of habitats ranging from foredune to dune scrub consisting of dense shrub cover 1-2 m in height, and were regularly captured over 1.0 km from the beach (Kiem 1979, Extine 1980). The studies by Kiem (1979) and Extine (1980) documented extensive use of microhabitats interior to the foredunes, and interior vegetation was used preferentially over foredunes during high population densities (Extine and Stout 1987).

Habitat Use by Exotic Species

Two exotic rodent species, the house mouse and black rat, were captured on the trapping transects, but they were uncommon compared to the native beach mouse and cotton rat. A total of three house mice and seven black rats were captured over the four quarterly trapping sessions on the habitat transects in this study. All house mice were captured in the foredunes and the black rats were captured in the stable dunes. These observations are consistent with my own personal observations trapping rodents on Anastasia Island at a variety of locations both prior and subsequent to this study (Chapter 2). By far, the vast majority of the house mouse captures I recorded on Anastasia Island (n=88) were in foredunes. Similarly, I recorded a total of 29 black rat captures on Anastasia Island in addition to those reported in this study, and the majority of these were in stable dunes.

Mus presumably originated in semi-arid regions east of the Caucasus Mountains of Asia and is well adapted to survive arid conditions (Watts and Aslin 1981). Wild forms of Mus typically occur in dry regions (Schwarz and Schwarz 1943) and tend to be uncommon in wooded areas (Whitaker 1968). Beach dunes such as those on Anastasia

Island are harsh environments with very limited availability of fresh water. The open, sandy structure of the foredunes is also similar to many other arid habitat types where Mus have been recorded. The most comparable study of habitat affinities of Mus was done on Wallops Island, Virginia (Kirkland and Fleming 1990) where the principal habitat of Mus was foredunes characterized by grasses and bare sand. Kirkland and Fleming (1990) proposed that Mus favors these habitat types because they are most similar to the ancestral habitat of this species. Because Mus inhabits fordunes that are also the primary habitat of the beach mouse, the potential exists for these two species to compete for resources (Chapter 2).

Black rats are widely distributed throughout Florida, where they occupy an enormous range of habitats including many natural areas (Layne 1974). Their preference for stable dunes probably results from a lack of suitable nesting sites on the primary dune. I have recorded several captures of black rats in primary dunes near the Matanzas Inlet bridge where the rats appeared to be nesting in the bridge structure and foraging out into the dunes. However, their overall scarcity in foredunes, their much larger size, and their more generalized dietary habits probably preclude the black rat from competing with the beach mouse on Anastasia Island.

Cotton rats were captured in all habitat types sampled in this study, illustrating their ability to use a wide range of habitat types both on Anastasia Island and throughout their range (Cameron and Spencer 1981). Cotton rat captures in primary dunes tended to occur in areas of dense panic grass (Panicum amarum) where cover was adequate; traps in very open sandy areas were less likely to take a cotton rat than traps places in dense grass. Although cotton rats occupy primary dunes, their divergent microhabitat affinities as well as their primarily herbivorous diet cause this species to pose little competitive threat to the beach mouse population.

Maintenance of a viable population of beach mice on Anastasia Island requires the maintainence of suitable habitat, and this chapter provides a quantitative basis for the management of beach mouse habitat on Anastasia Island. The transition zone is important for beach mice because it provides secondary habitat during population peaks and also provides a refugium from severe storms that may damage the primary dune. Maintenance of an open, sandy conditions in the transition zone is important for maintaining habitat suitability. Presently, many areas of transitional habitat are undergoing succession to hardwoods, especially in the larger natural areas at ASRA and FMNM. The expansive transitional habitat on Conch Island, the northernmost portion of Anastasia Island, is being rapidly colonized by wax myrtle (Myrica cerifera) and many acres of previously suitable beach mouse habitat are being lost annually.

Fire also played a role in maintaining the open character of transitional habitat on Anastasia Island, but fire suppression has allowed much of the open coastal scrub to succeed to the stable dune condition. Urbanization on Anastasia Island has proceeded to such an extent that burning to enhance beach mouse habitat is probably only feasible at either ASRA or FMNM.

Because essentially all of the dune habitat on Anastasia Island is either developed, undergoing development, or under public ownership, acquisition of habitat is a moot point. This situation underscores the need to ensure the preservation of adequate foredune habitat to sustain the beach mouse population. Automobile driving is permitted on the beaches of Anastasia Island. This activity causes the foredunes to be "pruned" by the automobile traffic, and creates an un-naturally straight dune line. This uniform dune line is less effective at dissipating wave energy than a naturally sloping and variable dune and probably contributes to the regular storm damage to the primary dune relative to the natural condition. Additionally, automobile driving on the beach prevents pioneering dune vegetation which, if allowed to become established, would trap sand and initiate the dune building process. Finally, driving in the dunes causes a direct loss of habitat, de-stabilizes the dune, and may occasionally result in the direct mortality of beach mice.

Table 3.1. Variables measured and techniques used in habitat evaluation at 220 trap stations in three distinct habitat types on Anastasia Island taken during Fall 1990.

Variable	Method
ground cover	ocular estimation of 1 m^2 quadrat
horizontal vegetation density	ocular estimation of density board
canopy cover	ocular estimation overhead
sea oat density	number of panicles per 1 m^2 quadrat
herbaceous species richness	number of species per 1 m^2 quadrat
distance to beach	measurement on aerial photograph

Table 3.2. Rodents captured and capture rate per 100 trap nights (in parentheses) on distribution transects located along the length of the island. Trapping was done in disturbed habitat adjacent to development and is compared to trapping in undisturbed habitat within FMNM. All transects were in foredune habitat and were run for 4 consecutive nights each during the summers of 1989 and 1990.

Year	Total transects	Trap nights	M. musculus	P. polionotus	R. rattus	S. hispidus
1989	31	1,240	11 (0.89)	73 (5.89)	1 (0.08)	2 (0.16)
1990	15	600	18 (3.0)	32 (5.39)	0 (0)	2 (0.33)
FMNM 1989	8	320	0 (0)	53 (18.4)	2 (0.62)	1 (0.31)
FMNM 1990	8	320	0 (0)	35 (10.9)	0 (0)	5 (1.56)

Table 3.3. Means (standard error in parentheses), F-statistic from analysis of variance, and level of significance for habitat variables measured on small mammal trapping transects in three vegetation zones on Anastasia Island. Subscript letters indicate statistical significance between vegetation zones for each variable.

Variable	Foredune	Transition	Stable dune	F	P
Ground Cover	45.3_a (1.1)	59.1_b (1.0)	85.2_c (2.8)	50.58	0.0001
Veg. density	4.4_a (0.5)	6.4_a (1.0)	17.5_b (3.2)	5.27	0.005
Herbaceous spp.	2.1_a (0.05)	3.7_b (0.07)	0.2_c (0.06)	321.5	0.001
Sea oat density	3.4_a (0.2)	0.1_b (0.01)	0.0_b (0.0)	222.3	0.0001
Canopy cover	0.0_a (0.0)	0.0_a (0.0)	66_b (2.5)	5525.1	0.0001
Beach distance	23.7_a (1.3)	80.3_b (0.8)	225.0_c (3.2)	3574.5	0.0001

Table 3.4. Non-parametric discriminant function classification of habitat variables collected at 220 locations within three distinct vegetation zones on Anastasia Island. Numbers in parentheses are percent classifications, and the error rate refers to the proportion of observations misclassified.

	Number (percent) classified into habitat type			
From type:	Foredune	Transition zone	Stable dune	Total
Foredune	384 (97.2)	11 (2.8)	0 (0)	395
Transition zone	12 (3)	388 (97)	0 (0)	80
Stable Dune	0 (0)	0 (0)	80 (100)	400
Totals	396 (45.2)	399 (45.6)	80 (9.1)	875
Error Rate	0.03	0.03	0.0	0.02

Table 3.5. Principal components analysis and variable loadings from factor analysis for habitat variables collected at 220 trap locations within three distinct vegetation zones on Anastasia Island. Rodent capture data were pooled over four quarterly trapping sessions conducted over one year.

	Principal component or factor				
Correlation matrix	1	2	3	4	5
Eigenvalue	2.36	1.29	0.99	0.82	0.39
Proportion of variance	0.39	0.21	0.16	0.13	0.06
Cumulative proportion	0.39	0.61	0.77	0.91	0.97
Uncorrelated factors of original variables					
Percent ground cover	0.59	-0.13	0.53	0.49	-0.31
Sea oat density	-0.27	0.78	0.24	0.41	0.30
Number herbaceous spp.	-0.40	-0.73	0.41	0.13	0.34
Vegetation density	0.36	0.27	0.64	-0.62	0.04
Canopy cover	0.91	0.11	-0.22	0.10	0.16
Beach distance	0.90	-0.22	-0.13	-0.003	0.26

Table 3.6. Habitat associations of four species of rodent captured at 220 trap locations within three distinct vegetation zones on Anastasia Island. Rodent capture data were pooled over four quarterly trapping sessions conducted over one year.

	Foredune	Transition zone	Stable dune	Totals
Number of stations	100	100	20	220
Trap nights	1,600	1,600	320	3,520
Rodent Species				
P. polionotus	325	149	0	474
S. hispidus	24	38	30	92
R. rattus	0	1	6	7
M. musculus	3	0	0	3
Totals	352	188	36	576
Expected Frequency by Habitat	88	47	9	
Chi-square	854.9	315.1	71.0	
Significance	0.001	0.001	0.001	

Table 3.7. Correlation matrix of rodent species captured at 220 trap locations within three distinct vegetation zones on Anastasia Island with the first five principal components from the habitat variables collected at the same 220 locations. Rodent capture data were pooled over four quarterly trapping sessions conducted over one year. Significant, positive correlation coefficients suggest a positive association of the species with the habitat variables described by each principal component and significant, negative correlation coefficients suggest negative associations with each component.

		Principal components				
Rodent species	Captures	1	2	3	4	5
P. polionotus	474	-0.03^{***}	0.15^{***}	0.15^{***}	-0.02	-0.16
S. hispidus	92	0.19^{***}	0.03	-0.05	0.01	-0.04
R. rattus	7	0.17^{***}	0.03	-0.08^{*}	0.10^{**}	0.05
M. musculus	3	-0.14^{***}	-0.26^{***}	0.24^{***}	0.18^{***}	-0.23^{***}

$*$ $P < 0.05$
$**$ $P < 0.01$
$***$ $P < 0.001$

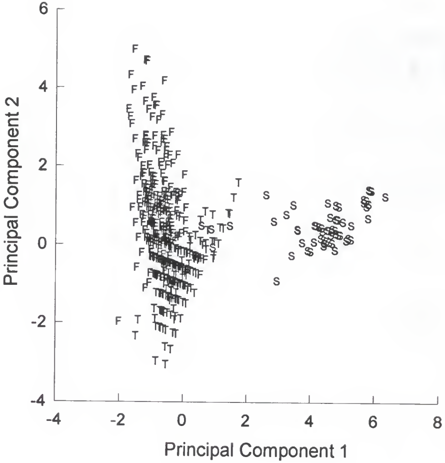

Figure 3.1. Plot of the first two principal components generated from the principal components analysis conducted on habitat variables collected in three distinct vegetation zones on Anastasia Island.

CHAPTER 4
RE-ESTABLISHMENT

Introduction

The Anastasia Island beach mouse historically occupied two barrier islands on the Atlantic coast of Florida; Anastasia Island and an unnamed island to the north extending from the city of St. Augustine to Jacksonville (Ivey 1949, Ivey 1959). Subsequently, the range of the Anastasia Island beach mouse was reduced to Anastasia Island alone (Humphrey and Barbour 1981, Humphrey et al. 1987). Why the Anastasia Island beach mouse was extirpated from the northern portion of the range was not documented, but severe hurricanes such as Donna in 1960 and David in 1979 that passed through the area may have contributed.

The Anastasia Island beach mouse population remaining on Anastasia Island is vulnerable to extinction. Much of the historically available habitat has been eliminated by development, the undeveloped habitat remaining in private ownership is fragmented and reduced in quality. Viable populations of Anastasia Island beach mouse may only occur at two locations, both large parcels under public ownership on either end of the island (ASRA and FMNM). House cats are known to be significant predators on small mammals such as beach mice (Churcher and Lawton 1989), and cats on Anastasia Island prey heavily on beach mice (Frank, 1992). Additionally, a chance event such as a hurricane could easily eliminate the entire beach mouse population on Anastasia Island.

The establishment of an additional Anastasia Island beach mouse population geographically removed from Anastasia Island would greatly reduce both the risk of catastrophic event such as a hurricane and random demographic losses.

The recovery plan for the Anastasia Island beach mouse (USFWS 1993) has identified reintroduction to its former range along beaches north of St. Augustine Inlet as high priority, and specifically identifies Guana River State Park (GRSP) as the most probable site for a reintroduction effort. The objective of this project was to establish the Anastasia Island beach mouse into previously occupied habitat at Guana River State Park. Methods were modeled after the successful reintroduction of the Perdido Key beach mouse (P. p. trissylepsis) on Perdido Key (Holler et al. 1989). Criteria for success of the reintroduction were survival, reproduction, and expansion of the introduced population at GRSP over a two-year scheduled monitoring period.

Methods

Guana River State Park (GRSP) was selected as the reintroduction site based on the availability of 6.5 km of undeveloped dune grassland habitat under public ownership. Automobile traffic is prohibited on beaches at GRSP and because of this, human-caused damage to beach mouse habitat is less compared to the beaches on Anastasia Island where vehicular traffic is allowed. Free-ranging house cats, common in dune habitats on Anastasia Island, are uncommon at GRSP. The remainder of the coastal dune habitat on the northern barrier island is under private ownership and either developed or subject to development. Johnson and Barbour (1990) provide a detailed description of vegetation typical of GRSP.

Although previous work had established that beach mice were not present at GRSP (Humphrey et al. 1987), we conducted a pre-reintroduction survey to determine what rodent species inhabited the dune system at GRSP. Three transects were established in the primary dunes running parallel to the beach, one at each end of the park and one in the middle. Each transect consisted of 20 stations spaced at 10-m intervals with two large Sherman traps placed at each station. Traps were baited with rolled oats and peanut butter and run for three consecutive nights for a total of 360 trap nights. One cotton mouse (P. gossypinus) and two cotton rats were captured during this trapping session.

Initially, two reintroduction sites were chosen at GRSP at the northern and southern ends of the dune system. However, a severe northeastern storm in October 1992 completely obliterated the dunes in the vicinity of the southern release site, so all beach mice were released at the northern location. This site was chosen based on the presence of a well-developed primary dune with minimal storm damage. Prior to relocation, a 5-m diameter release enclosure was constructed from aluminum sheeting (Holler, 1991). The purpose of the enclosure was to prevent mice from immediately dispersing following their release and to assist in establishing site fidelity. The enclosure was not intended to retain the mice for any length of time, and was dismantled after the initial release. Additionally, 50 kg each of rolled oats and sunflower seeds were scattered in the vicinity of the release site to aid the beach mice in adjusting to their new surroundings.

The mice used in the reintroduction were taken from two locations on Anastasia

Island; Fort Matanzas National Monument (FMNM) to the south and Anastasia State Recreation Area (ASRA) to the north. These two sites were selected to not adversely disrupt the population dynamics at a single location and to include a range of genetic variability into the reintroduced population. Trapping for donor mice on Anastasia Island was conducted from 9/24/92 to 11/12/92, and only healthy adult mice were selected for relocation. Each mouse was weighed, sexed, checked for reproductive condition, and individually toe-clipped for permanent identification.

A total of 55 mice were moved to GRSP from 9/27/92 to 11/12/92 , 37 from ASRA and 18 from FMNM. Twenty-seven of the 55 mice moved to GRSP were female; the remaining 28 were males (sex ratio 1:1). Forty-six beach mice were released at GRSP on 9/27/92 into the enclosure and were observed to burrow out of sight almost immediately. The remaining nine mice were relocated directly into the habitat on 11/12/94.

Post-release monitoring was conducted at GRSP quarterly from January 1993 through October 1994. These quarterly surveys were designed to document the distribution of mice throughout the park and provide a relative index of population density. Three transects were established at the north, south, and central portions of the park in primary dune habitat. Because the dunes were severely storm-damaged at the southern end of the park, the southern transect had to be placed landward of the previous primary dune, in habitat consisting of very dense grass. Each transect consisted of 20 stations spaced at 10-m intervals with two traps per station. Trapping was conducted for two or three consecutive nights per location. This short trapping period was chosen to minimize stress to mice that might have been repeatedly captured.

Concurrent beach mouse surveys were also conducted on Anastasia Island during winter, spring, summer, and fall 1994 to provide a comparison to the GRSP population. The transect configurations and trapping methods used were similar to those used at GRSP. Trapping was conducted at Anastasia State Recreation Area (ASRA) on the northern tip of Anastasia Island during winter, spring, and fall 1994 and at Fort Matanzas National Monument (FMNM) at the southern tip of Anastasia Island during summer 1994.

Age, sex, weight, and reproductive condition were determined for all mice captured, and mice were marked for individual identification. All mice captured were released at the trap station after processing. Trap results were reported as number of individuals captured per 100 trap nights to provide an index of population levels and allow standard comparison for unequal trapping effort.

Results

Distribution

The reintroduced population of beach mice expanded to include the entire 6.5-km length of dune habitat in the park by the first post-release survey on 2/8/93, four months after the initial releases. The population had almost certainly expanded beyond the park boundaries onto private properties both north and south of the park. Suitable habitat is available and beach mice were captured at the park boundaries. Beach mice were not distributed equally, and the transect at the southern end of the park typically had few or no captures compared to the transects at the middle and northern ends of the park.

Population Monitoring

On the first post-release census conducted 2/8/93, a total of 34 beach mice was captured in 520 trap nights. Sex ratio was equal, and juveniles were well represented in the population (N=10, 30%). Of the 14 adult female mice captured, 8 (57%) were either pregnant or lactating. Two mice originally released in October 1992 were recaptured approximately 1500 m and 2,900 m from the release site. The remaining beach mouse surveys at GRSP are summarized in Table 4.2. Capture success remained relatively high through the spring 1993 census, and then decreased to much lower levels through the remainder of the study. The fall 1994 census yielded a trap success of only 0.8 captures per 100 trap nights, the lowest capture success observed in the study. Trapping during this census was done during a severe northeastern storm, and the continuous heavy rain over the two-day census may have biased the results.

Additional mammals captured over the study included cotton rats, cotton mice, and house mice. Cotton rats were common throughout the park over the course of the study, especially at the southern end of the park in areas of dense grass cover. Cotton mice and house mice were much less common and were only captured occasionally throughout the study. Gray fox (Urocyon cinereoargentatus) and domestic cat tracks were observed in the dunes over much of the study area, and cats were frequently observed in the dunes and adjacent beach parking areas. The cats observed appeared to include both feral cats living within the park and free-ranging domestic cats emanating from residential areas adjacent to the northern and southern boundaries of the park.

Comparison with Anastasia Island Population

Beach mouse populations were more abundant at Anastasia Island than at GRSP during winter 1994, when trapping on Anastasia Island was begun (Figure 4.1). During the spring and summer censuses, populations at both locations were at approximately equal levels. During the final census in fall 1994, the GRSP population decreased relative to the Anastasia population, but capture success at both locations was low, possibly as a result of the inclement weather.

Discussion

Population Vulnerability

The objective of this project was to establish a secure population of the Anastasia Island beach mouse at GRSP, in the northern portion of the historic range. By this measure the project was a success. Following the releases in September, October, and November 1994, the population expanded rapidly to cover the entire length of the dunes in the park, and the population sustained itself over the two-year monitoring period. It is presumed that beach mice also are established outside the boundaries of the park because suitable habitat exists and there are no barriers to movement.

The net result of the establishment of a second population of the Anastasia Island beach mouse at GRSP has been to reduce the overall vulnerability of the supspecies to extinction. Extinction may result from a variety of factors including demographic, environmental, and genetic stochasticity, and natural catastrophes such as hurricanes (Schaffer, 1981, Gilpin and Soule, 1986). The Anastasia Island beach mouse population on Anastasia Island is susceptible to all of these factors. The Anastasia Island population is greatly reduced from historical levels due to extensive habitat loss, and habitat fragmentation has further reduced the viability of the original population by subdividing the previously continuous population into smaller sub-populations (Humphrey et. al., 1987). Population reduction and fragmentation has also increased the vulnerability of the population to deleterious genetic effects associated with small populations, potentially resulting in inbreeding depression.

Habitat Use

The distribution of mice within GRSP was consistent with the known habitat affinities of beach mice. Beach mice prefer early successional dunes with an abundance of open sandy areas, and beach mice were recorded in those sites with suitable habitat at GRSP during all surveys. However, the dune system at the southern end of the park was severely damaged during the October 1992 storm, and much of the primary dune habitat was lost. The remaining habitat consisted of very dense grasses with few bare sandy areas. Because beach mice tend not to occupy these types of habitats, it was not surprising that no captures were recorded at the southern transect in five of eight surveys. Captures were recorded there, especially during periods of high capture success, indicating that beach mice use these dense grassy areas intermittently, especially when populations are at high levels. A similar pattern of density-dependent habitat occupancy was documented in the southeastern beach mouse (P. p. niviventris, Extine and Stout

1987).

Differences between Anastasia Island and GRSP

Population levels at GRSP as indexed through trap night success were typically low compared to the population on Anastasia Island. This difference may be attributable to differences in habitat quality and quantity between Anastasia Island and GRSP, resulting in a reduced carrying capacity of the habitat at GRSP compared to Anastasia Island.

The physical structure, dune topography, and soil composition of the dunes at GRSP differs from Anastasia Island. The beaches and primary dunes on Anastasia Island are composed of fine white silica sand, while the sand at GRSP is darker, more coarse, with a higher shell content. Much of the dunes on Anastasia Island are low and comprise wide, rolling dune fields sparsely vegetated with grasses and annual herbaceous plant species, creating a wide band of acceptable beach mouse habitat. The dunes at GRSP are much narrower and steeper than those on Anastasia Island, with an abrupt transition from sparse dune vegetation near the beach to the denser woody vegetation of the coastal hammock. As a result, the range of acceptable beach mouse habitat may be more confined at GRSP than on Anastasia Island, and the overall quality of the habitat at GRSP appears to be low relative to Anastasia. In addition, because the northern beaches are narrow and steep, they are more susceptible to damage from severe storms, as was observed during the early part of this study.

Beach mice live in a very dynamic and unpredictable habitat, and they depend on their ability to recolonize habitats after a disturbance to persist. Population reduction and fragmentation on Anastasia Island, combined with the highly variable coastal environment, makes the remaining Anastasia population extremely vulnerable to extinction from any single factor or several factors acting in concert. The establishment of the GRSP population geographically separated from Anastasia Island has significantly decreased the probability of extinction of the subspecies. The addition of the GRSP population has increased the range of the subspecies, reducing the probability that a catastrophic event such as a hurricane will result in extinction. The establishment of the GRSP population has also increased the total beach mouse population, increasing the level of security against demographic and genetic stochasticity. Although the initial effort to expand the range of the Anastasia Island beach mouse to include the historically occupied northern beaches was successful, the true measure of the success of this effort will be the ability of this population to persist over the long-term.

Table 4.1. Distribution of Anastasia Island beach mice captures on transects spaced over the length of Guana River State Park from February 1993 through October 1994. Equal trap effort was expended at each transect, but trap effort differed between censuses. Data from the winter 1993 census is a subset of the trapping for that period (120 trap nights) selected to compare to the reduced trap efforts during subsequent censuses.

Season	North Transect	Middle Transect	South Transect
Winter 1993	1	2	3
Spring 1993	10	6	3
Summer 1993	2	1	0
Fall 1993	3	1	0
Winter 1994	2	3	0
Spring 1994	3	4	0
Summer 1994	5	3	2
Fall 1994	1	1	0

Table 4.2. Trap night effort, number of individual Anastasia Island beach mice captured, and captures per 100 trap nights from winter 1993 through fall 1994 at Guana River State Park, St. Johns County, Florida.

Season	Survey Date	Trap Nights	Number of Mice	Captures per 100 Trap Nights
Winter 1993	2/8/93	520	34	6.5
Spring 1993	4/29/93	360	19	5.3
Summer 1993	7/19/93	240	3	1.2
Fall 1993	11/7/93	240	4	1.7
Winter 1994	2/7/94	240	5	2.1
Spring 1994	4/20/94	240	7	2.9
Summer 1994	8/3/94	240	10	4.2
Fall 1994	10/12/94	240	2	0.8

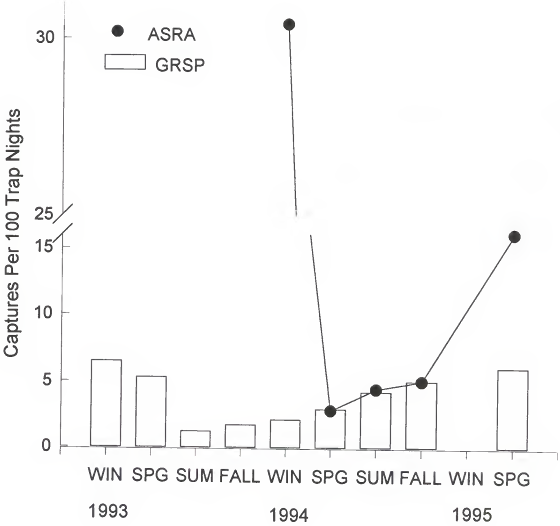

Figure 4.1. Comparison of trapping conducted at Guana River State Park and Anastasia Island State Recreation Area for Anastasia Island beach mice. Trapping was done on transects and the results converted to captures per 100 trap nights to allow for comparisons of unequal trapping effort.

CHAPTER 5
POPULATION VIABILITY ANALYSIS

Introduction

Population viability analysis (PVA) is a process that seeks to determine the degree of risk faced by populations of living organisms, allowing biologists to quantitatively assess the extinction risks faced by a particular population. The process commonly involves modeling both deterministic and stochastic processes that affect populations, and using the model results to predict the persistence time of a given population (Schaffer 1990). The difficulty in developing an accurate PVA for any given species involves assigning realistic model parameters based on data measured in the field or laboratory (Boyce 1992).

Because the PVA model relies on the best available biological information to make predictions, PVA predictions are only as accurate and reliable as the information gathered in the field. Many population processes such as density dependence and predator-prey dynamics are extremely difficult to quantify in the field, and their incorporation into PVA models can result in uncertainty in the model predictions. Similarly, estimation of the effects of stochastic environmental variation and rare catastrophes on population parameters in the PVA model is commonly educated guesswork. As a result, the conclusions obtained from PVAs should not be interpreted literally, but rather should be incorporated into adaptive management strategies aimed at preventing extinction.

In conducting a PVA for the Anastasia Island beach mouse, I incorporated the most reliable information available into the models. The mark-recapture study described in Chapter 2 was used to estimate the basic parameters of the population: agr structure, sex ratio, survivorship, fecundity, and population size. Population sizes were extrapolated from the habitat areas determined in Chapter 3 and population densities determined from Chapter 2. Hurricanes are an important environmental force affecting beach mice populations (Holler et al. 1989, Holliman 1983), and this aspect was included in the model through generalized predictions from hurricane models. In general, I remained conservative in the estimation of population parameters that were used in the model to portray a restrained picture of extinction risks.

In Florida, PVAs recently were conducted for the Florida panther (Felis concolor coryi), the Florida Key deer (Odocoileus virginiana clavium), and the Lower Keys marsh rabbit (Sylvilagus palustris hefneri), species of high public recognition with relatively well-known life histories. Results of the PVAs for these species suggest a poor probability of persistence of free-living populations, and intensive management was recommended in order to ensure the continued existence of these populations (Seal et al. 1990, 1989, Forys 1995). In the case of the Florida panther, a captive propagation program was subsequently initiated to augment the isolated population in southern Florida.

The purpose of this chapter is to integrate the data accumulated on beach mouse life history, population ecology, distribution, and habitat occupancy into a PVA. The resulting PVA will assist biologists and land managers to better assess the extinction risks faced by the Anastasia Island beach mouse and implement appropriate conservation strategies.

Methods

Beach Mouse Populations

The Anastasia Island beach mouse occupies four distinct geographical areas; ASRA, GRSP, private property on Anastasia Island between ASRA and FMNM, and the re-established population at GRSP (Chapter 2 and 4). To estimate total population size for the Anastasia Island beach mouse, a geographic information system was used to estimate habitat area at the three areas on Anastasia Island. Recent black and white aerial photographs of Anastasia Island were obtained from the University of Florida map library, and the outline of the island was digitized using PC-ARC/INFO (ESRI, Redlands, CA). The map was then rectified using known control points taken from 7.5-minute USGS quadrangle maps. Dune habitat known to be inhabited by beach mice was then digitized separately and overlaid onto the base map of the island. Detailed information on specific habitat types and occupancy by beach mice on Anastasia Island was available as a result of the field study, allowing a very accurate assessment of the range of habitats to be included in the analysis. Habitat area was calculated for each of the three separate areas as previously described, and combined for a island-wide estimate (Table 5.1).

Total estimated population size of beach mice was calculated simply by multiplying the habitat area as estimated above by the density of mice as determined through live-trapping. Because beach mouse densities varied on Anastasia Island, population size was calculated over the range of observed densities (Chapter 2). Beach mouse densities on Anastasia Island ranged from a mean low of 10 per ha to a mean high of 75 per ha, with 30 per ha an overall average (Chapter 2). Using these density estimates and the estimated habitat area from the GIS analysis, total estimated population size ranged from a minimum of 1,755 individuals to a high of 13,165 individuals, with the mean of 5,266 (Table 5.1).

Population Model

Model and model assumptions. The simulation model RAMAS/metapop (Akcakaya 1994) was used to conduct the PVA because it allowed great flexibility in the input parameters and was readily available. RAMAS/metapop allows the user to construct a model that incorporates spatial structure, multiple life stages, density dependence in survival and fecundity, random environmental variation in survival, fecundity, and carrying capacity, and incorporation of local and regional catastrophes. The modeling approach was to construct a very simple model based on data collected in the field and best described observations on the Anastasia Island beach mouse population over the two-year study. Major assumptions in the model include: a single life stage with common survivorship and fecundity, density dependence in beach mouse population growth rates, no migration between distinct populations, and catastrophes affecting all populations equally. The model parameters and major assumptions are discussed below.

Population parameters. Data collected on beach mouse survivorship and fecundity were not sufficiently detailed to allow separate estimates for adult and immature life stages since newborn and immature beach mice are not accessible to trap censusing. Thus, only the adult life stage was used to model populations with a common estimate of the intrinsic growth rate and survivorship for all simulations. Population parameters did not vary with over an individual mouses' life span. Survivorship and its standard error were estimated from mark-recapture data as described in Chapter 1. Separate estimates of survivorship were not available for the GRSP or private lands populations, so the values for ASRA and FMNM were used.

The intrinsic rate of growth, Ro, was calculated based on an age-structured Leslie matrix using data from both the ASRA and FMNM grids. The basis for this matrix was that the sex ratio at birth is 1:1 and females are capable of producing a litter of four every 22 days (16 pups every 90 days). The proportion of females either pregnant or lactating was estimated at 0.50 for both grid locations. Ro was estimated at 2.80, and that value used in all simulations (Table 5.2).

Because beach mice are short-lived and have high potential for reproduction, simple density dependence using the logistic function was incorporated into the model. Carrying capacity was arbitrarily set approximately two-thirds of the observed maximum population size as estimated by live trapping and total habitat area for ASRA, FMNM, and private property on Anastasia Island (Table 5.2). Initial abundances at each population were set at the approximate mid-range total population estimate for each population (Table 5.2). Environmental stochasticity was incorporated into the model by randomly varying the vital rates (survivorship and fecundity) in each time step based on the normal distribution. Deleterious genetic effects resulting from small population sizes were not included in the model because population sizes were generally much greater than those believed to cause genetic problems (Franklin 1981).

Spatial structure and metapopulations. The Anastasia Island beach mouse population was not modeled as a classic metapopulation, with extinction and recolonization of populations occurring regularly (Harrison 1994). Instead the total population consisted of three distinct populations incapable of interchange of individuals; GRSP, ASRA, and the FMNM/PRIVATE populations. GRSP is isolated from Anastasia Island by the St. Augustine Inlet, a fast-flowing body of water approximately 300 m wide. ASRA is also isolated from the rest of Anastasia Island by intense beachfront development in an approximately 1.0-km area. In this area, all dune habitat has been replaced by concrete revetment inhospitable to beach mice (Chapter 1). Thus, the population was modeled as three distinct populations without interchange.

Modeling catastrophe. Catastrophes were modeled as hurricanes and the effect of the catastrophe was to decrease the abundance of all life stages of all beach mouse populations. Catastrophes were range-wide, affecting all populations equally. Storm intensities ranged from Category I to Category V, with the proportion of total beach mouse mortality ranging from 10% to 95% (Table 5.3). These mortality estimates were based on the estimated storm surge associated with the various storm categories and the probability of dunes inhabited by beach mice being overwashed and destroyed. Storm frequency was estimated using HURISK, the National Hurricane Center Risk Analysis

Program (NOAA 1987). This computer program used data from 1886 to 1991 to generate landfall probabilities for the various storm categories at selected locations. HURISK was run with the target location of the St. Augustine Inlet, a location at the center of the range of the Anastasia Island beach mouse. The simulation was based on the historical occurrence of all storms passing within 75 nautical miles on the target location. Output generated by HURISK includes the mean return period for storms of varying intensities (Table 5.3).

Results

The simulation run without catastrophic effects to the populations indicated the beach mouse persisted for the duration of the simulation (Figure 5.1). The population remained stable around the estimated total carrying capacity of approximately 8,000 individuals. Individual runs of the population model indicated population lows in any one year as low as 3,000 individuals, and population peaks between 13,000 to 14,000 individuals. However, because the simulation was replicated 1,000 times for each time step, mean values of population size remained at or near carrying capacity. Varying survivorship and fecundity by as much as 50% in either direction did not alter the outcome of the simulation, indicating that the simulation was robust to these parameters. All four separate populations persisted throughout the simulations regardless of the differences in estimated carrying capacity at each site.

The simulations involving the catastrophic effects of hurricanes caused declines and extinctions in the populations as was expected, and storm impact probability was the most important parameter affecting the outcome of the simulations. The Category I storm predicted to occur once in every 10 years with only 10% mortality resulted in the extinction of the population within 40 years (Figure 5.2). The Category II storm, predicted to occur once each 24 years with 25% mortality, resulted in a persistent population over the simulation interval, but population levels were reduced to approximately 1,000 individuals (Figure 5.3). The Category III storm (one in 45 year interval, 50% mortality) reduced the population to approximately 3,000 individuals (Figure 5.4), the Category IV storm (one in 100 year interval, 75% mortality) reduced the population to approximately 5,000 individuals (Figure 5.5). The Category V storm (one in 290 year interval, 95% mortality) had little effect on the long-term outlook for the population relative to the no-catastrophe scenario (Figure 5.6).

To determine the sensitivity of the model to the various catastrophe parameters, both storm frequency and mortality effects were varied. The mortality rate had very little effect on the outcome of the simulations, because all populations persisted the length of the simulations. For example, reducing the mortality rate of the Category I storm from 10% to 5% extended the persistence time of the population only five years from 40 to 45 years. However, a reduction in storm frequency from one every 10 years to one every 20 years resulted in a persistent population over the 50-year simulation period. When the frequency of the Category V storm was reduced by 50% to once every 145 years, the population was persistent over the simulation despite the 95% mortality rate. When the Category V hurricane frequency was reduced by a factor of 100 to once every 29 years, the population was still persistent, although the final population size was reduced to approximately 2,000 individuals.

To better illustrate the sensitive aspect of storm frequency in the model, a range of storm intervals were compared while storm-caused mortality rate was held constant (Figure 5.7). The estimated 10% Category I storm-caused mortality was held constant and storm frequency was varied between 10, 25, 50, 75, and 100 year intervals. The simulation with a 10-year storm interval resulted in extinction of the beach mouse population within 40 years. Simulations with 25-year and above storm intervals resulted in populations persisting the length of the simulation (Figure 5.7).

Discussion

All conclusions regarding population persistence, both with and without catastrophic events affecting the population, are based on the assumption that the model accurately depicts Anastasia Island beach mouse population dynamics. In the absence of catastrophic storms, the model predicted a persistent population over the 50-year course of the simulation, and large fluctuations in minimum and maximum population size were typical within any year. The population without catastrophes remained stable around a mean of 8,000 individuals, but could vary between approximately 3,000 to 13,000 individuals during any year. The standard error around the mean population size typically ranged between 7,000 to 9,000 individuals.

The model results are generally consistent with the population dynamics documented through the field work conducted on Anastasia Island during 1989 to 1991 (Chapter II). Proper validation of this model would require extensive data that are not available on this species. However, based on the total population size of the Anastasia Island beach mouse and the species' high reproductive potential, it is not surprising that the simulated populations were persistent over the simulation period in the absence of catastrophic events. Theoretical calculations regarding minimally viable population size have determined that approximately 500 individuals may constitute a viable population over the long term (Franklin 1981). Clearly the Anastasia Island beach mouse population exceeds this threshold and, without catastrophic storms, is probably a viable population.

Despite the apparent agreement between model results and the observed patterns in the beach mouse population, the model is an overly simplistic representation of Anastasia Island beach mouse population dynamics. The population was modeled based on a single life stage (adult) being reproductively active. The variability in survival and fecundity was based on the proportional variability in the survival parameters estimated from the live-trapping study (Chapter 2). These estimates of survivorship were based on the recapture of uniquely marked individuals, and excluded that proportion of the population not accessible to the traps such as young in the nests. Estimates of survivorship also could not account for dispersing individuals leaving the population. Therefore, the survivorship parameter used in the model was probably biased in favor of increased survivorship relative to the actual number on individuals actually born into the population. These points all clearly illustrate the difficulties inherent in studying a small, nocturnal, and highly secretive mammal such as the Anastasia Island beach mouse.

There are also a wide range of ecological factors that certainly affect beach mouse population dynamics that were not incorporated into the model. Predation by both natural and exotic predators was not included in the model because this information was not available for estimation. Environmental stochasticity was incorporated into the model by varying the mean and variance of model parameters probably under-represented in the model because beach dunes are highly dynamic systems. Data on beach mouse food resource availability was not available for incorporation into this important aspect of the model, but considering the harsh nature of the dune ecosystem, environmental stochasticity is likely higher than estimated by the model.

The effect of catastrophic storms on the viability of the Anastasia Island beach mouse population was to reduce the viability of the population over the course of the simulation. However, an unexpected result of the modeling was that frequent, less severe storms may pose a greater threat to the persistence of the beach mouse population than do infrequent but more severe storms. For example, the Category I storm scenario resulted in the extinction of the entire population within 40 years, but the Category V storm only resulted in a slight reduction in mean total population size over the course of the simulations. Thus, a series of frequent but less devastating storms may pose a greater threat to the long-term survival of the Anastasia Island beach mouse rather than an extremely rare catastrophic storm.

Table 5.1. Estimates of population size of Anastasia Island beach mice at ASRA, FMNM, and privately owned lands over a range of densities recorded during live-trapping studies on Anastasia Island. Density on private lands was estimated to be one-half the density on public lands (ASRA, FMNM). Habitat area was estimated by digitizing aerial photographs of Anastasia Island.

SITE	ASRA	FMNM	PRIVATE	TOTAL
AREA (ha)	124.7	7.3	79.8	211.8
DENSITY		Estimated Population Size		
LOW (10/ha)	1,247	73	399	1719
MEAN (30/ha)	3,741	219	1197	5157
HIGH (75/ha)	9,352	547	2992	12891

Table 5.2. Population parameters used to simulate population persistence of the Anastasia Island beach mouse. Population growth rate and the standard error were held constant for all simulations. Carrying capacity (K) and initial population size (N) varied depending on location but were also held constant for all simulations.

POPULATION	Ro	Survivorship	Std. Error	K	N
ASRA	2.80	0.39	0.20	5000	3741
FMNM	2.80	0.39	0.20	500	219
PRIVATE	2.80	0.39	0.20	2000	200
GRSP	2.80	0.39	0.20	1000	1000

Table 5.3. Storm parameters used to model effects of hurricanes on the population viability of the Anastasia Island beach mouse. Predicted storm interval was estimated for the town of St. Augustine, approximately mid-point within the present range of the Anastasia Island beach mouse, using the hurricane prediction model HURISK.

Storm Category	I	II	III	IV	V
Predicted Interval in Years	10	24	45	100	290
Max. Sustained Wind (mph)	74-95	96-110	111-130	131-155	155+
Est. Storm Surge (ft)	4-5	6-8	9-12	13-18	18+
Effect on Beach Mouse Population (%	10	25	50	75	95

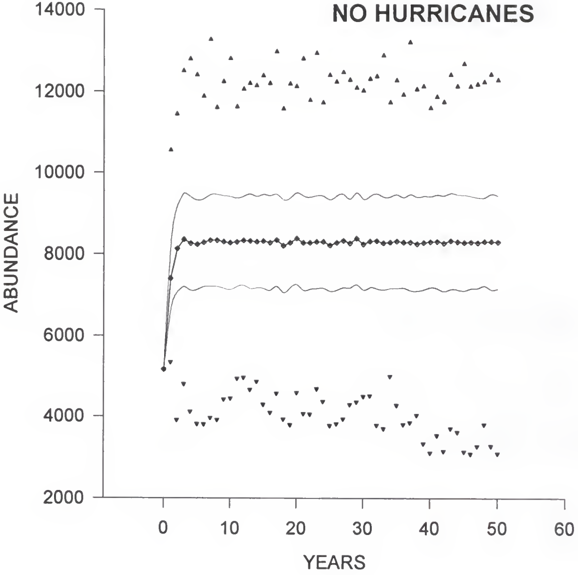

Figure 5.1. Results of RAMAS/metapop simulation for the Anastasia Island beach mouse without hurricane risk over a period of 50 years with 1000 replications. The dotted line indicates mean population size, solid lines indicate the standard error of the mean, and triangles indicate maximum and minimum values within each simulation period.

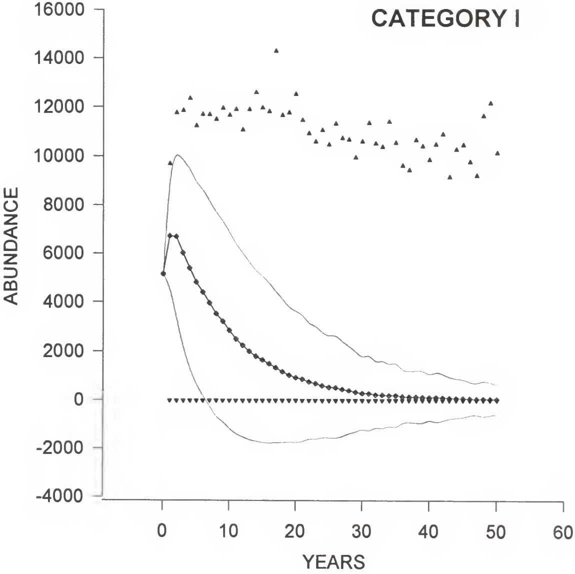

Figure 5.2. Results of RAMAS/metapop simulation for the Anastasia Island beach mouse with a Category I hurricane risk over a period of 50 years with 1000 replications. The dotted line indicates mean population size, solid lines indicate the standard error of the mean, and triangles indicate maximum and minimum values within each simulation period.

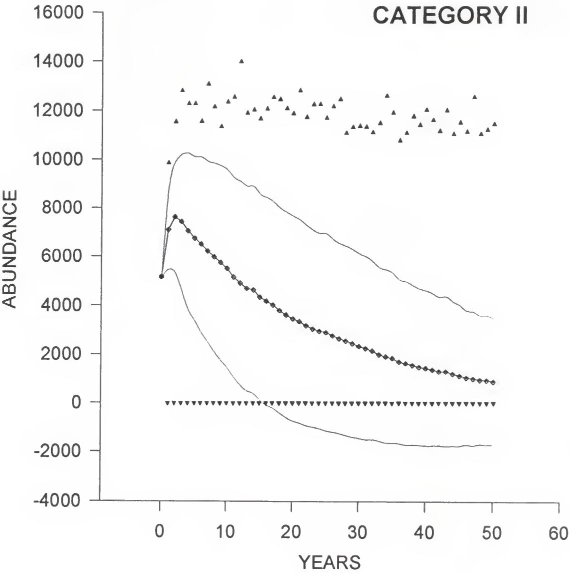

Figure 5.3. Results of RAMAS/metapop simulation for the Anastasia Island beach mouse with a Category II hurricane risk over a period of 50 years with 1000 replications. The dotted line indicates mean population size, solid lines indicate the standard error of the mean, and triangles indicate maximum and minimum values within each simulation period.

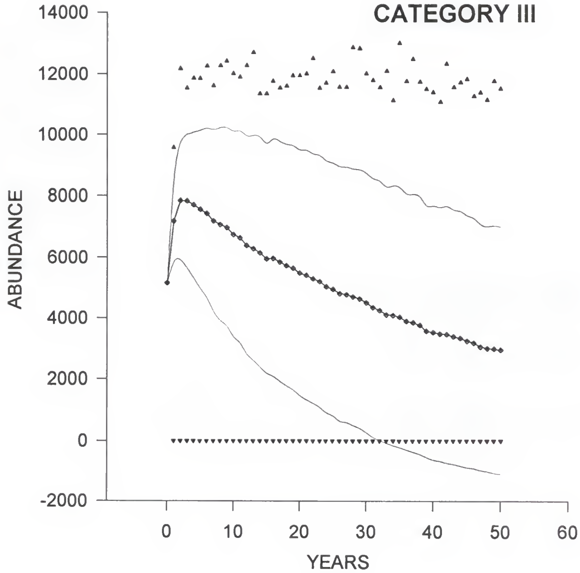

Figure 5.4. Results of RAMAS/metapop simulation for the Anastasia Island beach mouse with a Category III hurricane risk over a period of 50 years with 1000 replications. The dotted line indicates mean population size, solid lines indicate the standard error of the mean, and triangles indicate maximum and minimum values within each simulation period.

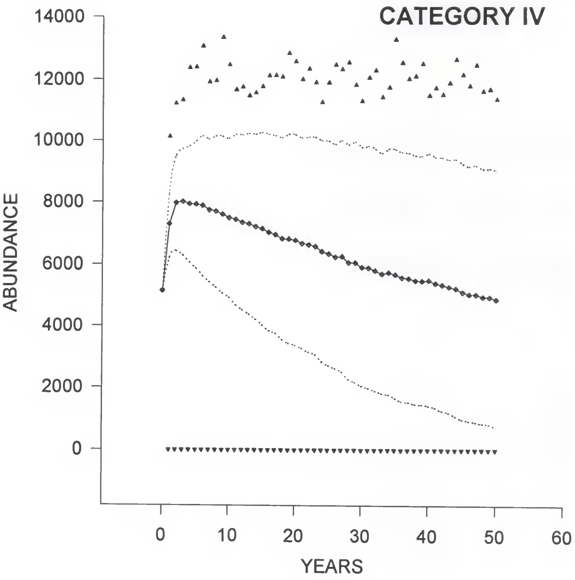

Figure 5.5. Results of RAMAS/metapop simulation for the Anastasia Island beach mouse with a Category IV hurricane risk over a period of 50 years with 1000 replications. The dotted line indicates mean population size, solid lines indicate the standard error of the mean, and triangles indicate maximum and minimum values within each simulation period.

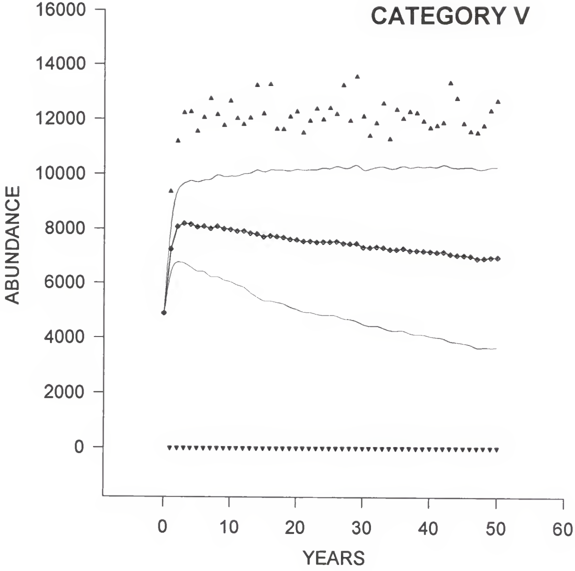

Figure 5.6. Results of RAMAS/metapop simulation for the Anastasia Island beach mouse with a Category V hurricane risk over a period of 50 years with 1000 replications. The dotted line indicates mean population size, solid lines indicate the standard error of the mean, and triangles indicate maximum and minimum values within each simulation period.

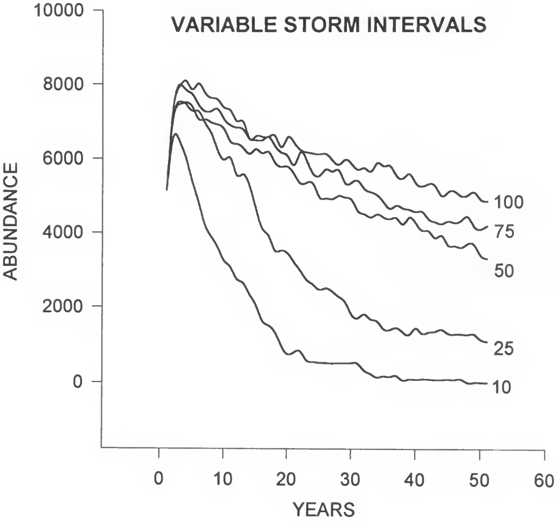

Figure 5.7. Results of RAMAS/metapop simulation for the Anastasia Island beach mouse illustrating the effect of storm frequency on population persistence time. Simulations were run with a constant storm mortality rate of 10% (estimated Category I mortality) and storm intervals of 10, 25, 50, 75, and 100 years.

CHAPTER 6
MANAGEMENT RECOMMENDATIONS

Management Philosophy and Goals

Preservation of the Anastasia Island beach mouse is a conservation bargain. In comparison to some of the more charismatic endangered species in Florida such as the Florida panther, the manatee (Trichechus manatus), or the Key deer, the long-term protection of the Anastasia Island beach mouse will be relatively easy. Because the majority of Anastasia Island beach mouse habitat has already been developed or acquired into public ownership, there will not be any staggering land acquisition programs to fund. Working with beach mice is simple; beach mice are abundant, small, easy to capture, easy to transport, and easy to maintain in captivity. With proper marketing, their sheer cuteness will ensure public support for their protection. This is an animal that can realistically be "saved" if the collective will of those charged with their preservation can be rallied. Thus, I believe that the primary management goal for the Anastasia Island beach mouse should be the use of creativity and flexibility to prevent their extinction.

Based on the predictions from Chapter 5, the Anastasia Island beach mouse population is likely to continue to persist in the absence of a catastrophic storm event, or a series of such events, so long as the background ecological conditions remain relatively static. However, it is unlikely that Anastasia Island will be spared a severe hurricane in the long term, so planning for the future of the beach mouse on Anastasia Island must incorporate the reality that a catastrophe will eventually strike. Because the original range of the subspecies and the amount and quality of habitat has been much reduced, the ability of the subspecies to survive a severe storm has been greatly compromised.

Thus, natural resource agencies and conservation groups responsible for the protection of the Anastasia Island beach mouse must choose an active management strategy that involves regular population monitoring, habitat management, captive propagation, appropriate environmental regulations, and public education should be implemented to ensure the survival of the taxon. A passive management strategy that relies on "ecosystem management" and the false assumption that the Anastasia Island beach mouse will be able to persist under current conditions will almost certainly result in the extinction of the subspecies.

The following management recommendations provide the framework to develop an active management strategy that accepts the high degree of risk faced by the Anastasia Island beach mouse as real. This strategy is based on the assumption that Anastasia Island is no longer an intact ecosystem, and a single-species rather than ecosystem approach is the only realistic paradigm to employ under the circumstances.

Proposed Management Actions

Population Monitoring

Beach mice are small, nocturnal, secretive animals that could easily become extinct without notice. For this reason, regular monitoring of the populations should be conducted to assess the health of the populations and guide future management action.

Monitoring should be conducted at all of the four populations: ASRA, FMNM, private lands on Anastasia Island, and at GRSP. Monitoring should be conducted annually at each location at a minimum; bi-annual monitoring would provide better information on the population status.

Monitoring methods should involve trapping transects placed in primary dunes, similar to the methods employed in Chapter 3. Transects 250-m in length with two traps placed at 10-m intervals should provide trap coverage for an adequate census. Transects should be spaced to allow adequate coverage of the area to be censused, with common sense and the area under consideration the best guide. For example, with the above technique a 1.0-km stretch of dunes could be sampled with two 250 m transects spaced 500-m apart. Smaller areas might require different transect configurations or possibly a single continuous transect.

Because beach mice are easily trapped, adequate census information can be collected in a short time. For this reason, trapping should be conducted for only two to three consecutive nights to reduce stress on individual animals. Trapping over a short duration will provide an index to population densities rather than a precise population estimate, but the index should be adequate for the purpose of monitoring population trends. Once determined, identical trapping methods should be used for all monitoring to allow easy comparison between locations and to assess trends in the populations over time.

Habitat Management

Maintenance of suitable habitat conditions is the key to protection of the Anastasia Island beach mouse population. Efforts to maintain the primary dunes on Anastasia Island and at GRSP should be a high priority, both for preservation of the beach mouse as well as for economic and aesthetic reasons. Activities that may compromise the integrity of the primary dune such as over-dune foot traffic, vehicular traffic both in the dunes and on the beach, inlet dredging, jetty construction, and beach re-nourishment should be carefully evaluated for negative impacts and corrective measures implemented. Stabilization of dunes damaged by severe storms should be implemented when necessary.

Because beach mice also use the transitional dunes, habitat management plans for beach mice must consider these habitats as well Succession of transitional dunes is evident in several locations on Anastasia Island, including Conch Island at ASRA and the areas of coastal scrub at FMNM. If allowed to succeed, these areas will cease to provide habitat for beach mice. For example, coastal scrub will succeed to a closed-canopy oak forest in the absence of periodic wildfires (Johnson and Barbour 1990), and the urbanization and fragmentation of the present landscape prevents a natural fire regime that once maintained these habitats. Areas where significant loss of beach mouse habitat is occurring as a result of succession to hardwoods should be evaluated for management action that may include prescribed burning to set back succession.

Domestic Cat Control

This study found predation by domestic cats to be a significant factor affecting the Anastasia Island beach mouse population, and management of domestic cats in beach mouse habitat may be the single most effective management technique available to reduce the vulnerability of populations to extinction. Domestic cats were found to use habitats well removed from development, and they pose a threat throughout the range of the Anastasia Island beach mouse. While it is probably an unrealistic goal to expect to eliminate all domestic cats from beach mouse habitats, this goal may be achievable on the publicly-owned parcels. A goal for the privately-owned lands would be to reduce the number of domestic cats in the habitat.

On public lands, cat control will involve physical removal of the offending cats using traps or shooting where allowable. This is standard park management policy on all public lands in the study area, and should be encouraged as a routine maintenance activity akin to emptying trash cans and cleaning toilets. Control of cats on private lands will require modifying pet owner behavior, because regulations on the restriction of the number and behaviors of free-ranging cats that citizens own probably are futile. Education on the damage cats inflict on wildlife in general, and the Anastasia Island beach mouse in particular, would be one possible means of enticing pet owners to either maintain cats indoors or reduce the number of cats they own. A program educating beachfront property owners not to feed free-ranging cats that are not their pets may also help reduce the numbers of cats in beach mouse habitat. Spay-neuter programs for cats could be brought into residential areas in an effort to reduce cat numbers.

Range-wide Management

Because the Anastasia Island beach mouse is vulnerable to extinction as the result of a catastrophic storm, maintenance of the most extensive geographic range as possible will provide the spatial separation of populations needed to prevent extinction resulting from a single storm event. This was the primary reason for the establishment of the GRSP population, and maintenance of the GRSP population should remain a high priority. Because the GRSP population appears to more vulnerable that the Anastasia Island populations, this population should receive more frequent monitoring than more secure populations. An effort to maintain or improve primary dune habitat at GRSP should be implemented wherever possible. The establishment of additional populations of the Anastasia Island beach mouse outside of the historic range should be implemented wherever possible to further decrease the vulnerability of the subspecies to extinction.

Catastrophe Planning

The greatest threat to the persistence of the Anastasia Island beach mouse over the next 50 years is the probability that a severe storm, or a series of severe storms, will result in their extinction. Whether or not a severe storm will eventually hit Anastasia Island is beyond question, but rather is a matter of when and how severe. Because of this fact, plans to prevent the extinction of the Anastasia Island beach mouse as the result of severe storms should be developed now. The Florida Department of Environmental Protection has proposed an emergency action plan that calls for an inter-agency rescue effort to be launched in the event of an impending storm (Alice Baird, personal communication). Under this scenario, once it has been determined that a storm will hit Anastasia Island, a team of trappers would capture several beach mice and transport them to a captive facility until the storm has passed. The captive beach mice would then either be released if the island remained largely intact following the storm or become the nucleus for a captive propagation program to re-establish the population if the storm caused a significant population reduction.

Efforts such as the development of the emergency action plan described above should be encouraged because these efforts could be the difference between extinction or survival of the taxon. However, a more certain alternative would be the establishment of a captive population at either a research facility or zoological park. Maintenance of a captive colony of the Anastasia Island beach mouse at a zoological park would be an inexpensive means of providing beach mouse hurricane insurance. Zoological parks would likely provide the funding needed to maintain the captive colony in return for the opportunity to display animals to the public. Perhaps if more people were to actually see a live beach mouse, more people would show concern for their preservation. If there was ever a creature that could dispel the myth of the "nasty rodent", it would be the Anastasia Island beach mouse. Thus, the exhibition of the Anastasia Island beach mouse at a public facility could only serve to better educate the public on the plight of the beach mouse, serve to protect the subspecies from extinction, and ultimately further the overall goals of beach mouse conservation in the long run.

REFERENCES

Akcakaya, A.A. 1994. RAMAS/Metapop: Viability Analysis for Stage-Structured Metapopulations. Applied Biomathematics, Setauket, New York. 185 pp.

ARC/INFO, Environmental Systems Research Institute, 1990. Arc/info User's Guide, Environmental Systems Research Institute, Redlands, California. 124 pp.

Bangs, O. 1898. The land mammals of peninsular Florida and the coast region of Georgia. Proceedings of the Boston Society of Natural History., 28:157-235.

Blair, W. F. 1951. Population structure, social behavior, and environmental relations in a natural population of the beach mouse (Peromyscus polionotus leucocephalus). Cont. Lab. Vert. Bio. University of Michigan, 48:1-46.

Bowen, W. W. 1968. Variation and evolution of gulf coast populations of beach mice, Peromyscus polionotus. Bulletin Florida State Museum, 12:1-91.

Briese, L. A. and M.H. Smith. 1973. Competition between Mus and Peromyscus polionotus. Journal of Mammalogy. 54:968-969.

Caldwell, L. D. 1964. An investigation of competition in natural populations of mice. Journal of Mammalogy. 45:12-30.

Caldwell, L. D. and J.B. Gentry. 1965. Interaction of Peromyscus and Mus in a one-acre field enclosure. Ecology, 46:198-193.

Cameron, G.N. and S.R. Spencer. 1981. Sigmodon hispidus. Mammalian Species. 158:1-9.

Churcher, P.B. and Lawton, J.H. 1989. Beware of well-fed felines. Natural History 7:40-46.

Dapson, R. W. 1979. Phenologic influences on cohort-specific reproductive strategies in mice (Peromyscus polionotus). Ecology, 60:1125-1131.

Davenport, L. B., Jr. 1964. Structure of two Peromyscus polionotus populations in old-field ecosystems at the Savannah River Plant. Journal of Mammalogy. 45:95-113.

Deevey, E.S. Jr. 1947. Life tables for natural populations of animals. Quarterly Review of Biology. 22:283-314.

Ehrhart, L.M. 1978. Pallid beach mouse. Pages 8-10 in J.N. Layne (ed.), Rare and Endangered Biota of Florida. Vol. 1. Mammals. Florida Committee on Rare and Endangered Biota, Gainesville, Florida. 52 pp.

Extine, D. D. 1980. Population ecology of the beach mouse, Peromyscus polionotus. Unpublished masters thesis, University of Central Florida: Orlando, Florida.

Extine, D. D. and I.J. Stout. 1987. Dispersion and habitat occupancy of the beach mouse, Peromyscus polionotus niviventris. Journal of Mammalogy. 68:297-304.

Forys, E.A. 1995. Metapopulations of marsh rabbits: a population viability analysis of the Lower Keys marsh rabbit (Sylvilagus palustris hefneri). Ph.D. thesis, University of Florida. 244 pp.

Frank, P.A. 1992. Conservation and ecology of the Anastasia Island beach mouse. Endangered Species Update. 9(12):9-10.

Frank, P.A. and S.R. Humphrey. 1992. Populations, habitat requirements, and management of the endemic Anastasia Island beach mouse (Peromyscus polionotus phasma), emphasizing the potential threat of exotic house mice (Mus musculus). Florida Game and Fresh Water Fish Commission, Tallahassee, Florida. 102 pp.

Franklin, I.R. 1981. Evolutionary change in small populations. Pages 135-194 in Conservation Biology: An Evolutionary-Ecology Perspective (M.E. Soule and B.A. Wilcox, eds.), Sinauer, Sunderland, Massachusetts.

Gentry, J. B. 1966. Invasion of a one-year abandoned field by Peromyscus polionotus and Mus musculus. Journal of Mammalogy., 47:431-439.

Gilpin, M.E. and M.E. Soule. 1986. Minimum viable populations: process of species extinction. Pages 19-34 in M.E. Soule, editor. Conservation Biology. The science of scarcity and diversity. Sinauer, Sunderland, Massachusetts.

Hall, E.R. 1981. The Mammals of North America. Vol. 1, John Wiley and Sons, New York, 690 pp.

Harrison, S. 1994. Metapopulations and conservation. Pages 111-128 in Large-Scale Ecology and Conservation Biology (P.J. Edwards, R.M. May, and N. R. Webb, eds.), Blackwell Scientific Publications, Oxford, England.

Hays, R.L., C. Summers, and W. Sietz. 1981. Estimating Wildlife Habitat Variables.

U.S. Department of Interior, U.S. Fish and Wildlife Service. Atlanta, Georgia. 111 pp.

Holler, N. R., D.W. Mason, R.M. Dawson, T. Simons, and M.C. Wooten. 1989. Reestablishment of the Perdido Key beach mouse (Peromyscus polionotus trissyllepsis) on Gulf Islands National Seashore. Conservation Biology., 3:397-404.

Holliman, D.C. 1983. Status and habitat of Alabama Gulf Coast beach mice, Peromyscus polionotus ammobates and P. p. trissyllepsis. Northeast Gulf Science. 6:121-129.

Humphrey, S. R. and D.B. Barbour. 1981. Status and habitat of three subspecies of Peromyscus polionotus in Florida. Journal of Mammalogy. 62:840-844.

Humphrey, S. R., W.H. Kern, and M.S. Ludlow. 1987. Status report of seven Florida mammals. U. S. Fish and Wildlife Service Technical Report No. 25, Jacksonville, Florida. 54 pp.

Humphrey, S.R. and P.A. Frank. 1992. Anastasia Island beach mouse. in Rare and Endangered Biota of Florida. Volume I, Mammals. (S.R. Humphrey, ed.), University Press of Florida, Gainesville, Florida.

Iverson, J.B. 1978. The impact of feral cats and dogs on populations of the West Indian rock iguana, Cyclura carinata. Biological Conservation. 14:63-72.

Ivey, R. D. 1949. Life history notes on three mice from the Florida East coast. Journal of Mammalogy., 30:162-164.

Ivey, R. D. 1959. The mammals of Palm Valley, Florida. Journal of Mammalogy., 40:585-591.

Johnson, A. F. and M.G. Barbour. 1990. Dunes and maritime forests. Pages 429-480 in Ecosystems of Florida, (R.L. Meyers and J.J. Ewel, eds.), University of Central Florida Press, Orlando, Florida.

Jones, T. C. and Coleman, B.J. 1981. Ecology of the feral cat in south- eastern Australia. I. Diet. Australian Wildlife Research. 8:537-547.

Kiem, M. H. 1979. Small mammal population dynamics and community structure in three east central Florida communities. M. S. thesis, University of Central Florida: Orlando, Florida. 212 pp.

Kirkland, G.L. and T.V. Fleming. 1990. Ecology of feral house mice (Mus musculus) on

Wallops Island, Virginia. Virginia Journal of Science. 41:330-339.

Konecny, M.J. 1987b. Food habits and energetics of feral house cats in the Galapagos Islands. Oikos 50:24-32.

Krebs, C.J. 1966. Demographic changes in fluctuating populations of Microtus californicus. Ecological Monographs, 36:239-273.

Kurz, H. 1942. Florida dunes and scrub, vegetation and ecology. Florida Geological Survey Bulletin, 23:1-154.

Lassle, A. M. and C.D. Monk. 1961. Some live oak forests of northeastern Florida. Florida Scientist. 24:39-55.

Layne, J.N. 1968. Ontogeny. Pages 148-253 in Biology of Peromyscus. (J.A. King ed.), Special Publication NO. 2, American Society of Mammalogists. 593 pp.

Layne, J.N. 1974a The land mammals of south Florida. Pages 386-413 in Environments of South Florida: Present and Past (P.J. Gleason, ed.). Memoir 2 Miami Geological Society. 452 pp.

Layne, J. N. 1974b Ecology of small mammals in a flatwoods habitat in north-central Florida with emphasis on the cotton rat (Sigmodon hispidus). American Museum Novitates, 2544:1-48.

Liberg, O. 1984. Home range and territoriality in free ranging house cats. Acta. Zool. Fennica 171:283-285.

Lidicker, W.Z., Jr. 1966. Ecological observations on a feral house mouse population declining to extinction. Ecological Monographs. 36:27-50.

Linzey, D.W. 1978. Parted Bay beach mouse. Pp. 19-20 in Rare and endangered biota of Florida. Vol. 1. Mammals. (J.N. Layne, ed.). University of Florida Presses, Gainesville, 52 pp.

McMurry, F.B. and Sperry, C.C. 1941. Food of feral house cats in Oklahoma, a progress report. Journal of Mammalogy. 22:185-190.

Menkens, G.E. and S.H. Anderson. 1988. Estimation of small-mammal population size. Ecology. 69:1952-1959.

Meyers, J. M. 1983. Status, microhabitat, and management recommendations for Peromyscus polionotus on gulf coast beaches. U. S. Fish and Wildlife Service. Atlanta, Georgia. 26 pp.

Nichols, J.D. and K.H. Pollock. 1983. Estimation methodology in contemporary small mammal capture-recapture studies. Journal of Mammalogy. 64:253-260.

Nudds, T.D. 1977. Quantifying the vegetative structure of wildlife cover. Wildlife Society Bulletin. 5:113-117.

Otis, D.L., K.P. Burnham, G.C. White, and D.R. Anderson. 1979. Statistical inference from capture data on closed animal populations. Wildlife Monographs, 62:1-135.

Pearson, O.P. 1964. Carnivore-mouse predation: an example of its intensity and bioenergetics. Journal of Mammalogy. 45:177-188.

Pollock, K. H. 1982. A capture-recapture design robust to unequal capture probability of capture. Journal of Wildlife Management. 46:757-760.

Pollock, K. H, J. D. Nichols, C. Brownie, and J. E. Hines. 1990. Statistical inference for capture-recapture experiments. Wildlife Monographs 107. 97 pp.

Pournelle, G. H. and B.A. Barrington. 1955. Notes on mammals of Anastasia Island, St. Johns. County, Florida. Journal of Mammalogy., 334:133-135.

Rand, A. L. and P. Host. 1942. Results of Archbold Expeditions, No. 45: Mammal notes from Highlands County, Florida. Bulletin American Museum Natural History, 80:1-21.

Rave, E.H. and N. R. Holler. 1992. Population dynamics of beach mice (Peromyscus polionotus ammobates) in Southern Alabama. Journal of Mammalogy. 73:347-355.

Schwarz, E. And H.K. Schwarz. 1943. The wild and commensal stocks of the house mouse, Mus musculus Linnaeus. Journal of Mammalogy. 24:59-72.

Seal, U.S., and R.C. Lacey. 1989. Florida panther population viability analysis and species survival plan. Captive Breeding Specialist Group, Species Survival commission/IUCN. 225 pp.

Seal, U.S., and R.C. Lacey. 1990. Florida Key Deer population viability assessment. Captive Breeding Specialist Group, Species Survival commission/IUCN. 105 pp.

Shaffer, M. L. 1981. Minimum viable populations for species conservation. Bioscience. 31:131-134.

Smith, M. H. 1968. A comparison of different methods of capturing and estimating numbers of mice. Journal of Mammalogy. 49:455-462.

Stout, I.J. 1979. Terrestrial community analysis. Vol I of IV: A continuation of base-line studies for environmentally monitoring space transportation systems (STS) at John F. Kennedy Space Center. Contract NAS 10-8986, Kennedy Space Center, Titusville, Florida. 73 pp.

Terman, C.R. 1968. Population dynamics. Pages 412-450 in Biology of Peromyscus. (J.A. King ed.), Special Publication No. 2, American Society of Mammalogists. 593 pp.

U.S. Fish and Wildlife Service. 1987. Recovery plan for the Choctawhatchee, Parted Key, and Alabama beach mouse. U.S. Fish and Wildlife Service, Atlanta, Georgia, 45 pp.

U.S. Fish and Wildlife Service. 1989. Endangered and threatened animals and plants; endangered status for the Anastasia Island beach mouse and threatened status for the southeastern beach mouse. Federal Register 54(91):20598-20602.

U.S. Fish and Wildlife Service. 1993. Recovery plan for the Anastasia Island beach mouse. U.S. Fish and Wildlife Service, Atlanta, Georgia, 19 pp.

Warner, R. 1985. Demography and movements of free-ranging domestic cats in rural Illinois. Journal of Wildlife Management. 49(2):340-346.

Watts, C.H.S. and H.J. Aslin. 1981. The Rodents of Australia. Angus and Robertson Publishers, Sidney. 321 pp.

Whitaker, J.O., Jr. 1967. Habitat relationships of four species of mice in Vigo County, Indiana. Ecology 48:867-872.

BIOGRAPHICAL SKETCH

Philip A. Frank was born on October 3, 1961, in Columbus, Ohio. He attended high school in Carmel, Indiana, graduating in May, 1979. He received a B.S. in zoology from Indiana University in Bloomington, Indiana, in 1984 where he developed his interests in the ecology and conservation of mammals. He entered the Master of Science program at the University of South Florida in Tampa in September, 1985. He conducted his master's research on small mammal ecology at the Archbold Biological Station working under the direction of Dr. James N. Layne. He completed his master's program in 1990. In August, 1988 he began work on his Ph.D. program at the University of Florida in Gainesville, Florida, under the direction of Dr. Stephen R. Humphrey, again focusing on the conservation and ecology of small mammals. After completing his field research and all course requirements, he left the university to work with the Florida Game and Fresh Water Fish Commission in the Florida Keys, where he remains at the present time. After receiving his Ph.D. in December, 1996 he intends to remain in the Keys where he will continue to work to preserve the biological diversity of that unique system.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Stephen R Humphrey

Stephen R. Humphrey, Chairman
Professor of Wildlife Ecology
and Conservation

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

John F. Eisenberg

John F. Eisenberg
Katharine Ordway Professor
of Ecosystem Conservation

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

George W Tanner

George W. Tanner
Associate Professor of Wildlife
Ecology and Conservation

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Melvin E. Sunquist
Assistant Professor of Wildlife
Ecology and Conservation

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Kenneth M Portier

Kenneth M. Portier
Associate Professor of Statistics

This dissertation was submitted to the Graduate Faculty of the College of Agriculture and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

December, 1996

Jack L. Fry

Dean, College of Agriculture

Dean, Graduate School